NAVAIR 00-80T-67

HANDBOOK FOR AIRCRAFT ACCIDENT INVESTIGATION

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Subject: RE: FOIA Case DON-NAVY-2021-011020; "Handbook for Aircraft Accident Investigation"

Ms. Meszler,

Confirmed. You are able to release in its entirety.

v/r,
Adam

Adam E. Hyams
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Subject: RE: FOIA Case DON-NAVY-2021-011020; "Handbook for Aircraft Accident Investigation"

Ms. Meszler,

I have received the document and will review today. From my initial look, I highly doubt there is anything which cannot be released to the public. I will have you an answer by COB.

v/r,

Adam

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Total number of pages in this manual is 162 consisting of the following:

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2-1 to 2-3	0				
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FOREWORD

The Naval aviation safety effort is based on the principle that safe operation is a basic function of command. Every aircraft accident affects readiness to some degree, and with the cost of equipment rising steadily, the loss of one of today's firstline aircraft represents a serious loss to the Navy and to the national economy.

Accident investigation is one of the fundamental elements in any sound program for the improvement of aviation safety. Conscientious, impartial investigation and accurate reporting of aircraft accidents are essential to our statistical recording system, cause and trend analyses, and our overall accident-prevention program. Aircraft accident investigators must analyze each accident to determine cause factors, adequacy of equipment, suitability of procedures employed, and the need for corrective action. The analyses, comments, and recommendations of the investigators are submitted via the chain of command for evaluation to determine steps to be taken to prevent similar occurrences.

The purpose of an accident investigation should be clearly understood in order to yield the greatest benefits. It is not to assess blame, nor is it solely to establish a single or primary cause factor. Few accidents result from a single cause. Most commonly, a sequence of events occurs, the elimination of any one of which could have prevented the accident. Therefore, to prevent future occurrences, it is imperative that all cause factors be determined. An incomplete investigation resulting in erroneous conclusions nullifies completely the only possible benefit which could be derived from a costly accident.

The investigation of the circumstances surrounding an aircraft accident is a methodical accumulation of small bits of formation which eventually form a pattern. The wreckage itself contains valuable evidence which, if correctly identified and assessed, will provide the certain cause factors. All factors, both mechanical and human, must be determined and their proper inter-relationship established. Only then can intelligent corrective action be taken.

The objective of this manual is to provide sufficient basic information, under a single cover, to enable an aircraft accident investigator to conduct a thorough and comprehensive investigation. An attempt has been made to minimize reference to specific documents which change periodically. The current directive governing Navy Aircraft Accident, Incident, and Ground Accident Reporting Procedures is a necessary adjunct to this handbook. In this manual, where reference is made to "the current OPNAV INSTRUCTION governing aircraft accident reporting procedures," OPNAV INSTRUCTION 3750.6 series applies.

W S Nelson

W. S. NELSON
Rear Admiral, U. S. Navy,
Commander, U. S. Naval Safety Center

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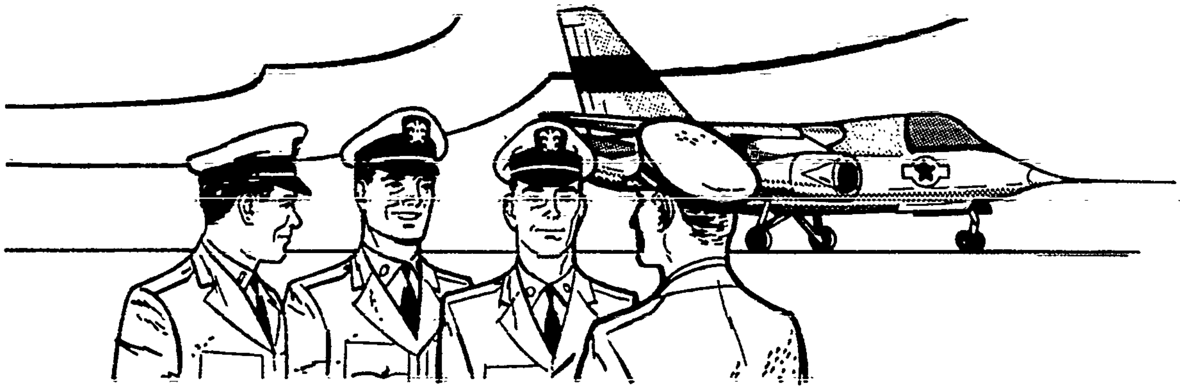


CHAPTER 1

COMMAND RESPONSIBILITY

1-1. COMMANDING OFFICER'S RESPONSIBILITY.

1-2. Commanding officers of activities and units operating naval aircraft have a twofold responsibility in aircraft accident investigation. These responsibilities are:

1. To appoint the members of the Aircraft Accident Board.

2. To assure that accident boards perform thorough and complete investigations.

1-3. SELECTION OF THE AIRCRAFT ACCIDENT BOARD.

1-4. The first responsibility requires the selection of the most qualified officers available to serve as members of the board. The Aircraft Accident Board, in the case of all aircraft accidents, incidents, flight hazards, and ground accidents that result in fatal or critical injury and/or destruction of a Navy aircraft, will consist of at least four officers, of whom two must be experienced naval aviators. Of the four members, the senior member should be a naval aviator or naval flight officer with wide experience or other qualifications warranting such an appointment, and he must be senior to the pilot in command involved; one member should be an officer well qualified in aircraft maintenance and engineering; one member must be a flight surgeon (a medical officer if a flight surgeon is not available); and the fourth member should be the aviation safety officer (a graduate of an aviation safety officer's course). When possible, at least one member of the board should be an experienced investigator.

1-5. Commanding officers should impress on the officers under their commands that every naval aviator is subject to assignment to an Aircraft Accident Board. Once this assignment is made, the members of the board, individually and collectively, become directly responsible for knowing the procedures and methods used in aircraft accident investigation. This knowledge must be acquired before an accident occurs. The unit aviation safety officer, as a permanent member of the Aircraft Accident Board, is responsible for assisting the commanding officer in assuring that all officers appointed to the board are cognizant of the contents of the current instruction governing aircraft accident reporting, OPNAV 3750.6 (Series), and of this handbook.

1-6. DESIRED CHARACTERISTICS OF THE AIRCRAFT ACCIDENT BOARD. The Aircraft Accident Board member, who shoulders a grave responsibility, must display extensive knowledge, determination, and perseverance. A successful investigation will invariably result in saving lives and equipment. When the qualifications of members of the board meet the spirit and intent of the OPNAV instruction governing aircraft accident reporting procedures, the accident investigation proceeds on a sound basis.

1. Permanency of Board. When possible, accident boards should be permanent organizations made up of carefully selected officers. The members must function as a team, and the knowledge and experience of each man should not be lost through frequent personnel changes. In certain cases, it will be necessary to organize an accident board to meet special circumstances. However, as many experienced accident board members as possible should be assigned to the new board. The problem will be unnecessarily complicated if all members of the accident board must learn the rules and procedures as well as investigate the accident.

2. Teamwork. A minimum four-member board of officers is specified for the investigation of a major aircraft accident because the details, complexities, and technical aspects require the combined efforts of a group of experienced and qualified officers. Thorough and comprehensive investigation requires the services of this four-member team and frequently requires the services of other specialized personnel. One of the great values of the team effort lies in the ability of the team to eliminate suppositions and opinions through discussions and cross-evaluations. The effectiveness of the investigation is in direct proportion to the degree of cooperating effort expended by all members of the board functioning as a team. The value of the group effort is lost when the board functions as a team only during the signing of the aircraft accident report.

3. Quality. Assuming that a commander has selected his most qualified personnel for the board, he must then fulfill his second responsibility – wherein he requires the board members to make a thorough and complete investigation. The commander must insure that the board is provided with every assistance during the investigation. It is mandatory that the board members have sufficient time to investigate the accident. They must not relegate the investigation to the status of a spare-time, collateral duty. In charging a board with its duties and responsibilities, the commander must emphasize that only a thorough and extensive investigation, combined with a complete and concise report, can produce acceptable results.

1-7. REQUEST FOR EXPERIENCED INVESTIGATORS.

1-8. Squadron commanders and officers commanding small naval aircraft units who are faced with a shortage of experienced accident investigators may request such personnel for accident board duty from the air group, wing, or appropriate superior organization. The quality of accident reports and consequently the entire naval aviation safety program benefits when the best available personnel are employed in accident investigations.

1-9. Requests for experienced investigators to serve on an accident board should be made through the commanding officer. Experienced officers should be selected for such "detached" duty only if they can be permitted to leave their normal responsibilities long enough to participate in a complete accident investigation.

1-10. PRIVILEGED STATUS OF INVESTIGATIONS.

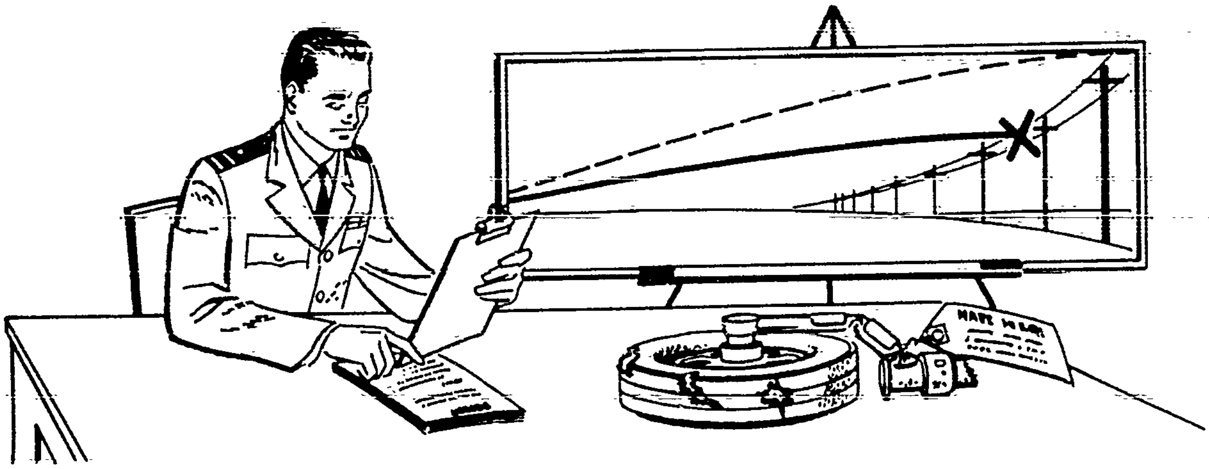
1-11. It is particularly pertinent to note that aircraft accident, incident, flight hazard, ground accident, and special aircraft investigations and reports, and the medical officer's reports of aircraft accidents, incidents, flight hazards, and ground accidents can be used only for analysis and statistical studies in the prevention of aircraft mishaps. They are therefore, deemed privileged documents. As such, they cannot be used as evidence, or to obtain evidence in determining the misconduct or line-of-duty status of deceased or injured person-

Figure 1-1. Layout of Wreckage on Hangar Floor

Figure 1-1. Layout of Wreckage on Hangar Floor

nel, as evidence to determine responsibility of personnel from the standpoint of discipline, as evidence to determine the liability of the government for property damage caused by such mishap, or as evidence before such administrative bodies as an aviator's evaluation board. The contents of an aircraft accident, incident, flight hazard, ground accident, or medical officer's report may not be appended to any other report as an enclosure or otherwise, unless the sole purpose of the other report or document is to prevent aircraft mishaps.

1-12. In many cases involving an aircraft accident, incident, flight hazard or ground accident, a separate investigation is conducted pursuant to the provisions of the Manual of the Judge Advocate General (JAGINST 5800.7A). The purpose of this investigation is to determine the cause of the mishap and gather pertinent evidence for use in legal, administrative or disciplinary actions resulting from the mishap.



CHAPTER 2

THE INVESTIGATOR

2-1. INTRODUCTION.

2-2. The aircraft accident investigator is the cornerstone of the naval aviation safety program. Detailed and precise investigations that reveal the immediate and underlying causes of aircraft accidents depend completely on the judgement, perseverance, and integrity of individual investigators.

2-3. Effective action to prevent future accidents cannot be taken unless the true causes of past accidents are known. Accurate statistical evidence, based on the reports of aircraft accident boards, is absolutely necessary to reveal trends in accident causes and to enable higher authority to remedy the causes through design changes, operational procedure revisions, provision of additional weather and navigational facilities, or other corrective measures.

2-4. A high rate of aircraft accidents attributed to "undetermined" causes can cast suspicion on the statistical data on accident causes and can lead to serious omissions in the naval aviation safety program. Most of the accident investigation burden still falls on squadron members who do not have the benefit of formal training in this difficult and specialized task. Therefore, accident board members must prepare themselves conscientiously and thoroughly for this duty.

2-5. With the current trend toward more sophisticated aircraft and aircraft systems, the cost per accident has greatly increased. The greater complexity of modern aircraft places increased demands on the knowledge and character of all investigators, regardless of their training, if the true causes of an accident are to be uncovered.

2-6. The first requirement of self education for aircraft accident investigation duty is to do it before an accident occurs. The inexperienced investigator must realize that the problem of complete investigation will be unnecessarily complicated if he attempts to master the general rules of procedure at the same time he is conducting an investigation.

2-7. This handbook is intended to serve as a first element in this self-education program, as well as to provide a reference for experienced investigators. New investigators should study this manual immediately after their assignment to an accident board and use it as a foundation on which to build a vigorous program to improve their knowledge. The best procedure to follow in a self-education program is to study all available literature on flight safety, past accidents, and the operation and functioning of naval aircraft and their equipment, and to observe the investigations of other units.

2-8. QUALITIES OF A SUCCESSFUL INVESTIGATOR.

2-9. In addition to following a vigorous self-education program, each member of an accident board must possess or develop certain fundamental qualities to be a successful investigator.

1. An Open Mind. The ability to refrain from making a decision until all the facts are obtained, sorted, evaluated, and considered is perhaps the most important qualification an aircraft accident investigator can have.

2. A Capacity for Hard Work. The investigation of an aircraft accident requires large amounts of elbow grease and midnight oil.

3. Common Sense. The requirement that an investigation be conducted in a planned and orderly manner necessitates that the members of the board be endowed with plain, ordinary horsesense.

4. Integrity. The investigator must be above influence of any kind from any source and report the facts that are determined from the investigation.

5. Faith. The investigator must have faith in the fact that the cause of the accident can be determined.

6. Curiosity. The investigator must possess or develop a strong curiosity if he is to determine the cause of an aircraft accident.

7. Perseverance. The investigator must have the ability to ferret out every factor until the ultimate cause is determined.

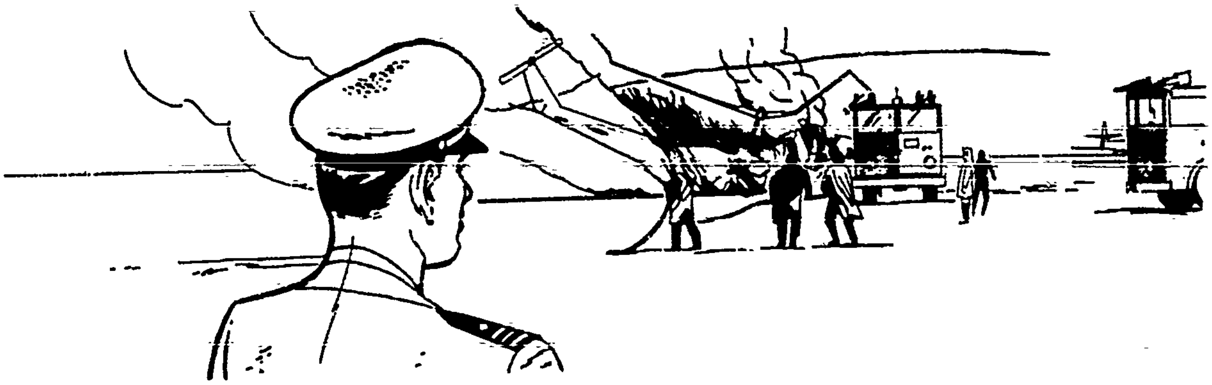
8. Basic Knowledge. The investigator should have a broad basic knowledge of this handbook, the field of aviation, and the type of aircraft involved in the accident.

Figure 2-1. A Quality of a Successful Investigator is the Capacity for Hard Work

9. Tact. The investigator must be tactful in his contacts with all of the individuals who are parties to the investigation. The natural pride of pilots, crewmen, squadron mates, support personnel, and supervisory personnel sometimes results in a reluctance to supply needed information. Tact and diplomacy on the part of the investigator are required to overcome this reticence.

2-10. NONPUNITIVE NATURE OF ACCIDENT INVESTIGATIONS.

2-11. The sole duty of the aircraft investigator is to discover and report all relevant facts so that the true causes of aircraft accidents can be revealed and the knowledge used to prevent similar accidents. The new investigator should understand completely from the outset that the information derived from his work is of a privileged nature and can be used only to improve flying safety within the military services and in general aviation. Aircraft accident reports cannot be used in any legal action that might result from an accident. The privileged status of the information acquired and the report is one of the investigator's most important tools in obtaining complete cooperation from witnesses and in determining the causes of an accident.



CHAPTER 3

ESSENTIALS OF A GOOD INVESTIGATION

3-1. QUALITIES OF A GOOD INVESTIGATION.

3-2. Successful investigations have certain essential features in common. Every investigator must apply these essentials of good investigation in his work as well as become familiar with them in theory.

1. Promptness.

a. Get to the scene of the accident as soon as possible, before the evidence is disturbed. Prevent unnecessary moving of the wreckage.

b. List witnesses for later questioning.

c. Follow clues while they are fresh.

2. Thoroughness.

a. Examine all evidence in minute detail.

b. Take nothing for granted.

c. Do not jump to conclusions.

d. Follow every clue to the limits of usefulness.

e. Question all witnesses or persons having knowledge of any phase of the accident.

f. Preserve wreckage or evidence until the investigation is satisfactorily completed.

g. Operate on the theory that there is no limit to the amount of effort justified to prevent the recurrence of one aircraft accident or the loss of one life.

3. Organization.

a. Conduct a planned investigation.

b. Lay out logical procedures tailored to the accident under investigation.

c. Follow each course in a systematic manner.

d. Avoid hasty conclusions that tend to limit the scope of the investigation.

4. Accuracy.

a. Guesses, rumors, or half truths are

unacceptable in an accident report.

b. Statements must be verified or subject to verification.

c. Theories are useful only in the absence of facts and must be well substantiated.

d. All evidence must be recorded accurately.

3-3. GOOD NOTE-TAKING. In any one investigation, the investigator becomes aware of hundreds of unrelated facts. It is obvious that he cannot resort to memory alone to retain these points in subsequent reporting. Extensive notes are a must in all investigation work. Each investigator must develop his own particular methods suited to his own needs and working procedures. For this reason it is not possible, nor would it be desirable, to outline a standard procedure for taking notes during an investigation. There are certain basic underlying principles which should be common to all note-taking procedures and these will be briefly discussed for the investigator's guidance.

3-4. The investigator will soon discover the desirability of recording complete notes as the investigation progresses. In this manner, the note-taking will not only serve to consolidate his own thoughts (or possibly suggest new avenues of investigation) but will also serve as a permanent record for reference. When the investigation takes place over an extended period of time, it sometimes is helpful to review and consolidate the day's notes after the completion of the working day. The important point to remember is that the notes should be made when the fact or item is developed and that one must not trust to memory to make the note at some later date. Unless this is done, situations will arise when the investigator will be unable to check out some point or theory that he had observed or determined earlier in the investigation. A tape recorder is an ideal means of recording observations and witnesses' statements as they are developed.

3-5. When an investigator arrives at the scene of an aircraft accident, certain facts are evident. Once the wreckage is moved or is transported to another location for further examination, additional damage is usually incurred. It is extremely important, therefore, that adequate notes be made during the various phases of investigation so that later misleading indications can be explained or discarded. The investigator should not rely too heavily on photographs, because it often develops that the desired photograph was never taken or poor photographic techniques have rendered the picture useless.

3-6. The investigator should bear in mind that his report will generally be divided into a factual part and an analytic part. The notes, therefore, should contain information pertaining to each portion. For example, let us assume that the investigator is making notes on his examination of a failed wing panel. As factual information, his notes would include data on the general overall damage and the station locations of the various breaks, tears, and score marks on the skin, stringers, etc. In addition, notes would include data on the type and direction of landing that caused the failure, the relationship of one failure with another, and whether the overall wing damage was consistent with all facts developed during the investigation. Simple sketches can be used to good advantage in recording the factual data, and numbered paragraphs can be keyed to the sketches to record the analysis or evaluation of the notes. As analytic information, the notes must include data regarding a detailed study of the factors involved in order to determine the solution.

3-7. ACCIDENT CAUSES.

3-8. A major precept of good investigation is to consider every possible cause or factor that may have contributed to an accident. Even if the available evidence seems to point conclusively to one cause, all the factors that led or contributed to this cause must be revealed and properly categorized. Whether the apparent probable cause is mechanical or human failure, it is imperative that every factor that could even remotely be considered a possible cause be studied and analyzed.

3-9. Obviously, this approach will result in more work and will often lead to a prolonged investigation, a bulky report, and perhaps a degree of speculation. Nevertheless, this method has been proved to be sound. All the effort put into an investigation leads to the accident board's analysis of the evidence to determine whether possible causes are probable or actual causes. Only after this determination can all the factors be recorded in their proper relationship to the primary accident cause and appropriate recommendations for corrective action made.

3-10. The proper classification of cause factors as "primary" or "contributory" after they have been revealed by thorough investigation cannot be overstressed.

3-11. CONCLUSIONS BASED ON FACTS.

3-12. The conclusions of an aircraft accident investigation must be based on factual information. A degree of speculation and intuition is often helpful to an accident board in its effort to follow every possible lead and conduct a thorough and complete investigation. However, the conclusions of the board must be substantiated by facts, all of which are contained in its report. The factual evidence and conclusions in the accident report must be presented so as to eliminate other possible conclusions and to give a clear picture to the reviewing authorities.

3-13. If the cause factors cannot be backed completely by facts, the report must state this positively. It is then permissible to list the most probable causes and the factors which, in the best judgement of the board, contributed to these probable causes.

3-14. SIGNIFICANCE OF THE ACCIDENT REPORT.

3-15. The accident report is the foundation of the naval aviation safety program. It is the basis for all accident-rate statistics, which determine the immediate goals of the safety program. It is also the basis of preventive action taken to avoid the recurrence of particular types of accidents.

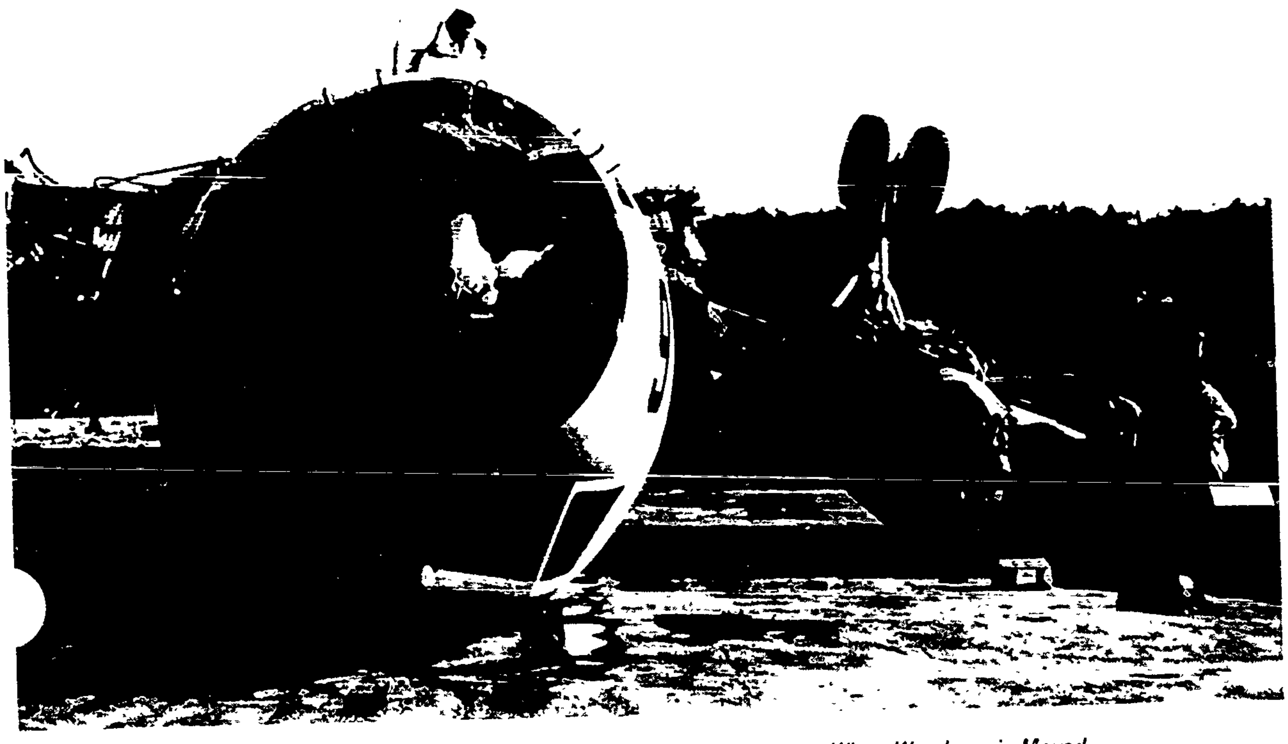


Figure 3-1. A Complete Record Prevents Loss of Evidence When Wreckage is Moved

3-16. The responsibility of the investigators who prepare these reports cannot be overemphasized, and their attitude toward this duty is of extreme importance.

3-17. The accident report must contain sufficient information, written in narrative form and in simple language, to enable reviewing authorities to determine exactly what happened, why it happened, how the investigator determined what happened and why, and the basis for recommending corrective action to prevent recurrence.

3-18. RESPONSIBILITIES OF THE SENIOR BOARD MEMBER.

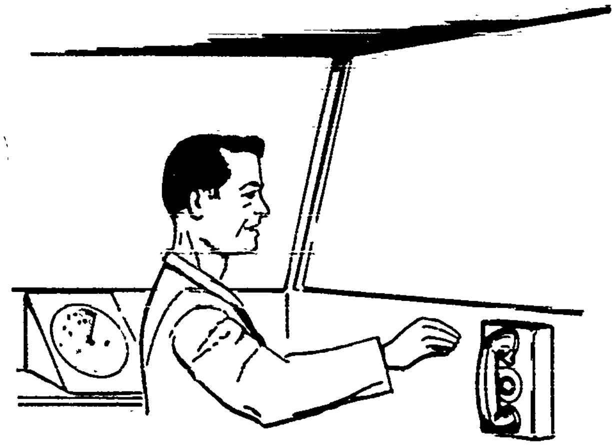
3-19. The senior member of the board automatically becomes responsible for the training of members of the board, for pre-accident planning, and for the conduct of any investigations assigned to the board. He must also insure that all members of the board:

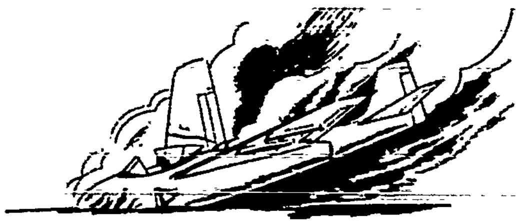
1. Realize the importance of detailed familiarity with directives pertaining to accident investigation and reporting.

2. Know the procedures to be used immediately following an accident and the obligation of board members to visit the scene of the accident as quickly as possible.

3. Understand the procedures used in accident investigation.

4. Are impressed with the vital importance that good investigation and reporting plays in the accident prevention program.





CHAPTER 4

PRE-ACCIDENT PLANNING

4-1. PRE-ACCIDENT PLAN.

4-2. An aircraft accident board's pre-accident plan, as the name implies, is the plan prepared by the board to be initiated on receipt of information that an aircraft accident has occurred. This plan is drawn up into a formal document that specifies the organization to be used during an investigation and contains instructions for all personnel who are directly or indirectly concerned.

4-3. The senior board member is responsible for distributing copies of the plan to everyone concerned with its implementation. He must make certain that they understand their duties and are ready to proceed in an orderly fashion if an accident occurs. It is highly desirable that all personnel understand the overall rescue and investigation plan and be familiar with the functions, capabilities, and limitations of all other personnel and groups that will participate in the operation.

4-4. Pre-accident organization may differ widely, depending on such factors as type of installation, operating procedures, aircraft, location, and mission. Planning must provide flexibility for periods away from station and on deployment. All aviation safety officers and senior board members are responsible to their commanding officers for seeing that the best coordinated and most workable pre-accident plan for any given organizational setup has been prepared, circulated, and kept current. These officers should use tact and diplomacy in insuring that all essential personnel and equipment outside their organizations are prepared to augment the plan, reporting any discrepancies to their commanding officer.

4-5. RESCUE OPERATIONS.

4-6. Rescue of the pilot, crew, and passengers in an aircraft is the paramount function taking immediate priority over the accident board's investigation at the scene of the accident. Consideration should also be given to the civilian population, further property damage, and the public interest. Normally, this is the responsibility of the crash and rescue organization of the ship or station. Coordination of the board's pre-accident plan with the crash-rescue plan of the installation must be assured by the senior board member so that an accident involving both activities will receive prompt and proper rescue and investigative action.

4-7. THE CRASH ALARM SYSTEM.

4-8. A crash alarm system is required by order of the Department of Defense to notify all essential personnel of an aircraft accident. There are two components to the crash alarm system, the primary and the secondary alarm circuit. Stations on the primary circuit, which are specified by regulation, must be connected by intercom. These stations are: the control tower, crash fire and crash ambulance stations, and the operations dispatcher's desk. The principal duty of all activities on the primary circuit is the preservation of life.

4-9. The aircraft accident board will be tied into the secondary alarm circuit, which generally operates through the telephone switchboard and is triggered through the operations dispatcher's desk. The procedures for passing the word through this circuit are usually determined by the installation commander.

4-10. DETAILS OF THE BOARD'S PRE-ACCIDENT PLAN.

4-11. The pre-accident plan of the board and its parent unit is put into effect immediately on receipt of the crash alarm signal. To be effective, this pre-arranged plan must provide for the following.

1. Notification by an activity on the primary circuit must be provided for in case a squadron fails to receive word of the accident through the crash alarm system.

2. A crash grid map to facilitate location of the wreckage is necessary. Such a grid map covering the airfield and the surrounding area for a radius of more than 15 miles should be issued to all essential personnel and activities and kept current as to local road conditions. Delays have been experienced in the past because drivers of vehicles proceeding to the crash scene have not been informed of road repairs, detours, and washouts. Details are of great importance on the grid map. Landmarks and farms should be identified in the local terminology to allow crash information telephoned from private citizens and the local authorities to be translated into directions for all military personnel.

3. Transportation to move investigative personnel to the crash scene should be alerted according to the pre-accident plan as soon as the alarm is received. Ground vehicles, liaison aircraft, and/or helicopters may be required. Several vehicles are often needed to transport all members of the required investigative group, and these are usually formed into a convoy. The convoy leader should be well acquainted with the roads in the area, and his vehicle should be equipped with two-way radio. The convoy should form at a pre-designated point before moving to the crash area.

4. Wreckage must be preserved for investigative purposes. Guards should be included in the pre-accident plan and should move to the crash scene in the convoy to assure that sightseers and souvenir hunters do not pick up or destroy valuable evidence. Personnel must not be allowed to move the wrecked aircraft, except for rescue purposes, until the senior member o the board indicates that the wreckage investiga is complete or the commanding officer of the installation orders it removed for safety reasons. Guards should be equipped with sleeping bags, rations, and proper clothing so that they may stay at the accident scene for a prolonged period.

5. Civilian guards may be employed to preserve the wreckage if the crash occurs at a great distance from a military installation. Local and state authorities are sources from which to obtain this assistance.

6. A checkoff list of persons and groups to be notified, containing their addresses as well as telephone numbers, is necessary. The checkoff list should include: the squadron commander, the safety officer, the members of the accident board, the chaplain if death is involved, the pu' information officer, the leading or duty chief, others as recommended by the board.

7. The squadron duty officer is the key man in setting the pre-accident plan into motio when notification of the accident is received. He

s the responsibility of alerting the persons on ue checkoff list and has custody of all kits and equipment that should accompany the investigative party to the accident scene. The duty officer uld also keep an accurate log of all events per- ing to the accident.

8. Members of the accident board should be aware that they are pre-assigned as investigators of the accident.

9. Specific duties should be delegated to each investigator so that all necessary duties will be performed without duplication of effort.

10. Potential investigators must be made familiar with directives and publications that will expedite their investigation.

11. A general plan for organization of the investigators and the general procedures to be followed is necessary. The senior member of the board must control the investigation, and this is most easily accomplished by pre-arranging the procedures to be followed.

12. An investigator's kit must be available and ready for use (see Appendix A).

13. Pre-arrangements must be made with

Figure 4-1 Confusion at Accident Scene Can be Avoided by Thorough Pre Accident Planning

the nearest photographic laboratory to supply a photographer on scene when required with minimum delay.

14. Reconstruction of the wreckage is a common practice for hole-in-ground type accidents. It is time consuming and requires valuable space that is normally used for other purposes. Parts of the aircraft are often difficult to identify, and experienced people will be required to assist in this operation.

15. An up-to-date list of persons and organizations able to provide technical assistance should be maintained.

4-12. PRACTICE RUNS.

4-13. A well-executed pre-accident plan may well be the difference between the success and failure of an investigation. Aircraft accidents have a habit of occuring when they are least expected and, more often than not, the atmosphere at the scene is one of excitement, congestion, and confusion. An investigator, especially if he is a new member of the board, may find himself with so many things to do that he does not know where to start. Important details may be overlooked if the pre-accident plan is not thorough and complete. Therefore, everyone concerned must be familiar with his duties.

4-14. One of the best methods of insuring board preparation is to have practice runs. Spot checks should be made to see that all documents, charts, and equipment are ready for immediate use.

4-15. SPECIAL CONSIDERATIONS FOR AIR STATION ACCIDENT BOARDS.

4-16. Naval air station accident boards must give special attention to accidents involving transient aircraft in the vicinity of the air station. Current OPNAV instructions provide that when an aircraft accident, incident, flight hazard, or ground accident occurs at a location where it cannot be handled expeditiously by the reporting custodian, he will request the commandant of the naval district in which the mishap took place to assign responsibility for investigating and reporting the mishap to the nearest naval air station. The commandant of the naval district may pass this request to the commander, Marine Corps air bases (east or west), when the mishap takes place near a Marine Corps air activity.

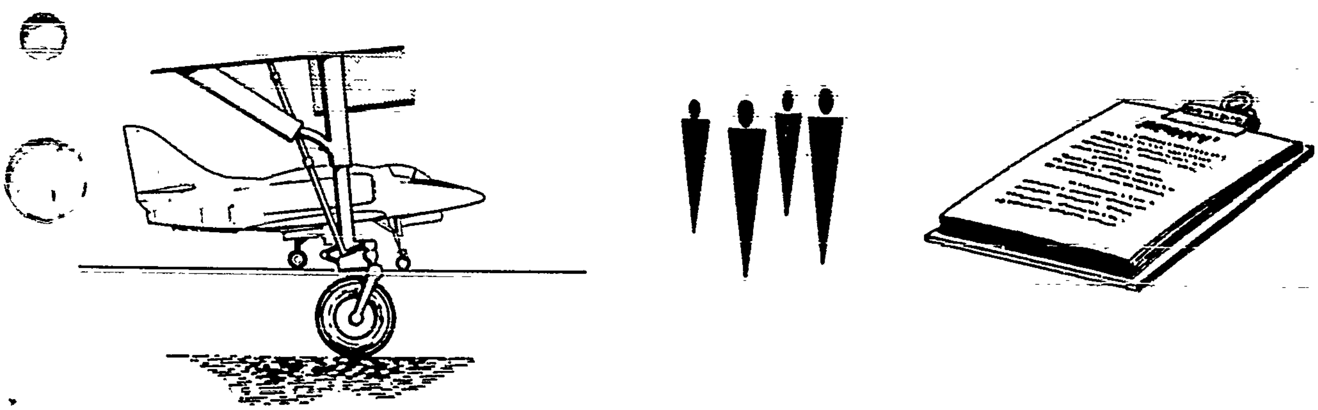
4-17. To meet these requirements, every air station accident board must be prepared to make immediate preliminary investigations when an accident occurs close to the air station and involves transient aircraft. This action will:

1. Assist the accident board of the reporting custodian;

2. Prepare the groundwork necessary in the event the reporting custodian requests the station to convene the accident board;

3. Provide proper security of the wreckage and existing evidence.

4-18. It is incumbent on air stations to have an adequate supply of equipment for issue to guards assigned to the security of wreckage. This equipment should protect personnel from the elements peculiar to the location of that station; i.e., sleeping bags of the type required in that climate, tents if deemed necessary, mosquito netting and repellent, foul-weather clothing, etc. This equipment should be properly packaged in a central location for immediate issue. Planners should check station special services as a source of this equipment



CHAPTER 5

ORGANIZATION OF AN INVESTIGATION

5-1. INTRODUCTION.

5-2. A successful investigation of an aircraft accident largely depends on good organization. Aircraft accident investigation is a specialized job and, like medical diagnosis, entails a microscopic search for unknowns. Every factor, however remote or small, must be discovered, weighed, and considered to reconstruct what actually occurred. It would be impossible to accomplish a task of this magnitude without good organization and planning, conscientious execution of the plan, and preparation of thorough records of each step in the investigation.

5-3. Past records indicate that members of aircraft accident boards who lacked the zeal, ability, or knowledge essential to organizing and conducting a good accident investigation have failed to determine the primary cause factor. This in turn has contributed to a series of similar accidents.

5-4. There are basic criteria for the detailed procedures of investigating, but the methods may be as varied as the number and type of aircraft accidents that occur. No magic rules of organization and procedure exist that will fit every accident. Basically, an aircraft accident investigation should be organized and tailored to fit each accident. The board members, however, should follow several general principles that are fundamentally sound as they organize each investigation. The purpose of this chapter is to highlight these principles so that they will be used as the foundation for each aircraft accident investigation. If members of the accident board have thorough knowledge of these principles and apply them to the investigation, it will proceed on a well-organized basis.

5-5. AREAS OF INVESTIGATION.

5-6. There are three general areas of investigation that can lead to the determination of accident causes: material, personnel, and records. The areas are broad in nature and often closely related by the various aspects of the accident. The material area includes all parts and components of the aircraft, and any other material factors which affected the accident (such as support facilities). The personnel areas include all those persons who were related to, or concerned with, the flight, such as flight crew, maintenance personnel, controllers, and witnesses. The records area includes all records concerned with the aircraft and the flight—records such as maintenance, airframe and power plant records, flight crew and aircraft logs, training and operational documents, medical histories of the flight crew, records of radio transmissions, etc.

5-7. When all the areas listed above are present, the investigation proceeds without handicap, but there are many accidents in which one or more of the general areas are not available. From the preceding information there are two important principles to be emphasized:

1. The information gained from one area can be used to substantiate information gained from another.

2. In the absence of one or more areas of the investigation which are normally scrutinized, it becomes increasingly important that the remaining available areas and factors receive additional emphasis during the course of the investigation.

5-8. TYPES OF AIRCRAFT ACCIDENTS.

5-9. There are many categories of aircraft accidents but for the purpose of organization, the majority fall into one of the following general types.

1. No survivors—extreme disintegration of the aircraft (hole-in-the-ground type).

2. The survivor type.

3. No survivors or wreckage available.

4. Minor accidents.

Each of the general types of accidents listed above may be further categorized by the type of failure precipitating the accident. These categories in-

Figure 5-1. Investigators at this Accident Scene Recovered Throttle Linkage shown in Figure 5-2.

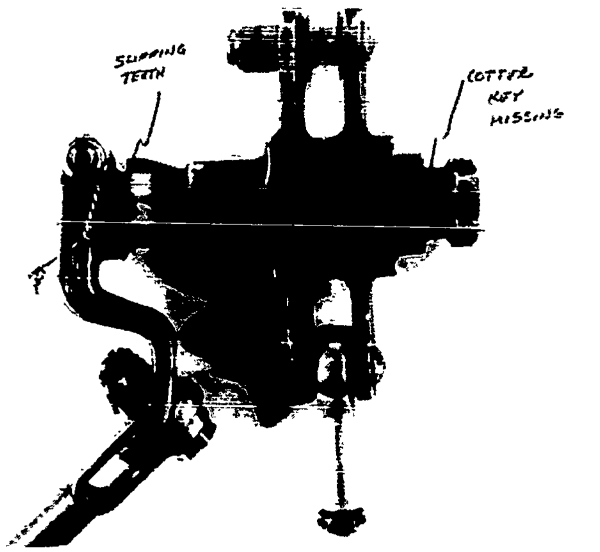


Figure 5-2. Throttle Linkage Determined to be Cause of Accident Shown in Figure 5-1

clude structural failure, control failure, power failure, pilot factor, weather, maintenance error, error of other facilities or personnel, etc. Each of these categories, by their name, indicates the area and initial emphasis for the investigator.

5-10. ACCIDENT WITH NO SURVIVORS–EXTREME DISINTEGRATION OF THE AIRCRAFT STRUCTURE. This type of accident presents the supreme challenge to the accident investigator. Since there are no survivors, the position of the controls, configuration of the aircraft, its attitude, and speed at time of impact, etc., must be determined from the wreckage, records, and witnesses. The following steps are tantamount to thorough and complete investigation.

1. All witnesses to the accident should be located. The investigator will be able to find these witnesses by conducting a house-to-house search in those areas which may have significance to location or time.

2. Every piece of wreckage must be recovered and inspected by qualified personnel. Sift the dirt from the hole, utilizing a 30- to 50-man search party to gather up all the small pieces. Conduct a search along the flight path for parts which may have broken off prior to impact. When the wreckage is recovered, the most qualified personnel available should check the parts for identification, evidence of fire, unusual failure, control positions, trim settings, power settings, fuel system malfunctions, etc. An inventory to ascertain that all vital parts are present can easily be accomplished in the process of placing parts in the aircraft plan form for systematic analysis.

3. Make accurate wreckage distribution, flight path, and impact diagrams. Where parts are very small and widely scattered, the general location of the small parts may be indicated by a shaded area. Location of major components should be indicated, together with directions and distances from the point of impact. The flight path should be determined from ground indications, witnesses' statements, and wreckage distribution.

5. Check all available records. This should include the pilot's log and qualifications, aircraft and engine logs, maintenance discrepancy reports, flight plan, weight and balance, weather, and recordings of radio transmissions.

5. Review all operational, training, and maintenance procedures which could have affected the pilot or aircraft.

6. Request data on similar accidents from the Naval Safety Center (see Appendix G).

5-11. THE SURVIVOR TYPE OF ACCIDENT. This type of accident may also result in the total disintegration of the aircraft. In this case there is a vital witness available who can shed some light on the series of events leading up to the accident. The survivor can point out the most profitable avenues of investigation, the configuration of the aircraft, control positions, impact angles, etc. The following steps are a general outline of the routine to be followed.

1. Obtain complete statements from the survivor or survivors. These statements must be as detailed as possible. Then question the witness after reviewing his statement. Unusual circumstances may require investigators to ask leading

questions in order to insure that all pertinent information is included.

2. The wreckage must be recovered and inspected in the manner described above. The wreckage will confirm the survivor's statements and fill in any points not covered by his statements.

3. Witnesses' statements must be obtained.

4. Wreckage distribution, impact, and flight-path diagrams must be prepared.

5. All records available must be reviewed.

6. Review all operational, training, and maintenance procedures which could have affected the pilot or aircraft.

5-12. NO SURVIVORS OR WRECKAGE. The accident in which there are neither survivors nor wreckage presents a difficult problem. In this case the following steps are mandatory, and each must be thoroughly scrutinized for there is no other source of information available.

1. Review all witnesses' statements.

2. Interview all personnel concerned with the flight of the aircraft.

3. Carefully study all records, logs, personal histories of the crew, flight plans, navigation data, weather data, etc.

4. Study all operational and maintenance procedures which may have affected the aircraft.

5. Request information on similar accidents from the Naval Safety Center.

5-13. THE MINOR TYPE OF ACCIDENT. The minor accident, because of its nature and results, should not receive minor effort in finding the cause or reporting the events. Indeed, a minor type of accident may require more work, more time, more substantiating data, and more knowledge to establish cause factors than a more serious accident. The board that fails to solve the causes of minor accidents or recommends the wrong corrective action might well be signing a death warrant for another naval aviator. The importance of thoroughness and diligence on the part of an investigator can never be overemphasized.

5-14. TASK ORGANIZATION OF THE AIRCRAFT ACCIDENT BOARD.

5-15. Every aircraft accident board is faced with the problem of separating the various investigative tasks. The senior member of the board has the responsibility of assigning these tasks to individual members. There are many tasks to be performed, and each member may seemingly be overburdened by this load of duties. Proper organization, persistence, and cooperation among the board members will eliminate this impression.

5-16. The senior board member should endeavor to assign individual board members to general areas of the investigation in which their training and experience will be most useful. The task assignments should be made by the senior member at the scene of the accident, following the preliminary investigation.

5-17. One system of task organization that has proved successful is listed below. It is important to note that this organization may be changed if another type seems more feasible for a particular accident.

1. Operational task group.

2. Personnel task group.

3. Material task group.

4. Aero-medical task group.

Each task group may consist of one or more individuals, depending on the requirements of the particular accident. Each group, however, should be headed by a member of the aircraft accident board.

5-18. OPERATIONAL TASK GROUP. The op-

operational task group should be under the direct supervision of the senior member of the accident board. The group has two major functions.

1. It acts as a coordinating group and as record and information center for the investigation. Members of the other task groups should keep the operational task group constantly informed of the progress of their investigative work. This information is used by the senior board member to coordinate and direct the accident investigation. The senior member should insure that information that may highlight avenues of investigation for the other groups receives wide and rapid dissemination. This can be accomplished easily in most cases by a short daily meeting to review the progress being made by each group. The senior member should also collect and evaluate the reports, data, and statements from all the groups and organize the paper-work that will make up the accident report. All information will then be in good form, ready for the use of the whole accident board in its final analysis and evaluation.

2. It performs the part of the investigation concerning the operation of the aircraft before the accident. The operations task group should gather data on clearances, weather, weight and balance, facilities, procedures, techniques, communications, and all other information that might reveal any mishandling of, or trouble aboard, the aircraft.

5-19. PERSONNEL TASK GROUP. The personnel task group is primarily concerned with the questioning of witnesses, surviving crew members, and all other personnel who may be even remotely connected with the series of events leading up to the crash. These people will provide the investigator with information concerning what they actually saw or heard, when, where, and often why. A list of these people may include maintenance and flight personnel, friends of the pilot, other squadron pilots, witnesses to the crash, tower and GCA personnel, crash crew, and others who may have been monitoring the movements of the aircraft. For more complete information regarding witnesses, see Chapter 9.

5-20. MATERIAL TASK GROUP. The material task group is concerned with the wreckage and all facts that can be derived from analysis of the various parts. A great deal of painstaking observation of details and recording of factual data is necessary before attempts can be made to determine how a failure occurred and its relationship to the accident. Much of this work must be accomplished in the region of the accident site. The remainder should be completed in a well-lighted hangar or building where the wreckage can be conveniently placed for close examination. For more complete information regarding witnesses, see Chapters 7 and 8.

5-21. AERO-MEDICAL TASK GROUP. The aero-medical task group is involved with a highly specialized field of investigation, and it is essential that the flight surgeon direct the efforts of this group. He will probably be the only individual available who has the training and knowledge to investigate the area of human failure and be able to call in the necessary specialists to assist. Because human failures are involved in almost all accidents, it is recommended that this task group be organized for all major accidents. (Present evidence indicates that many material failures are pilot induced or the result of error of other personnel.) Complete details are presented in Chapter 11.

5-22. PHASES OF INVESTIGATION.

5-23. It is important to maintain continuity of thought and effort through the entire investigation, from the preliminary investigation until the submission of the final report. This is most readily accomplished by dividing the overall tasks into phases. The five basic phases of the main investigation are:

1. Phase I - basic examination

   a. Records

   b. Support facilities (if involved)

   c. Personnel factors

d. Material factors

e. Aero-medical factors

2. Phase II - consolidation of data

3. Phase III - analysis

4. Phase IV - conclusions

5. Phase V - recommendations

5-24. SEQUENCE. Phases I and II are complementary and should be handled concurrently. If the data and information revealed during the investigation are consolidated and evaluated on a definite schedule, the basic examinations of the task groups can proceed more logically. A thorough analysis of the data on hand is necessary if the interplay between Phases I and II is to be complete; however, Phase III, the analysis phase, is not primarily concerned with this type of continuing evaluation. Phase III refers to a formal meeting of the complete aircraft accident board at which the final analysis of the evidence is made. The last three phases must necessarily be accomplished separately and in order. A complete description of the work to be accomplished in each phase follows.

5-25. PHASE I. This phase of the investigation is based on the requirement for thorough examination of all aspects of the accident. This entails a detailed investigation by the task groups into all factors that conceivably could have influenced the accident.

5-26. PHASE II. This is the phase most frequently overlooked by aircraft accident boards, although it is one of the most vital steps of the investigation. During the first phase of the investigation much factual information has been acquired and substantiated by charts, notes, diagrams, statements, photographs, etc. These data must be consolidated into usable form as soon as possible after being gathered. During the consolidation, all information must be assembled, segregated, edited, and combined in a form suitable for analysis. Until this consolidation has been accomplished, complete and accurate analysis of the data is difficult.

5-27. In addition to assisting in the final analysis, the consolidation-of-data phase also provides timely knowledge of any missing documents, errors, omissions, or lack of proof. Once these errors and omissions are known they should be remedied immediately by the investigative task group concerned before material proof is lost in the recovery of the wreckage or before important witnesses leave the area.

5-28. PHASE III. The third phase of the investigation is the analysis of data. A careful analysis of the data compiled during Phases I and II of the investigation is required to establish the basic cause of the accident. This analysis should be a joint effort of all members of the aircraft accident board. All members of the board must participate to insure full utilization of the combined experience and knowledge of the board members.

5-29. In those cases where careful investigation and analysis does not establish the primary cause of the accident, the analysis of all available information will disclose probable causes and possible contributory factors. These factors will form a basis for conclusions and recommendations relative to the accident. In most accidents, conclusions and recommendations based on probable cause factors can be highly effective in aircraft accident prevention.

5-30. PHASE IV. OPNAV instructions require that the results of the detailed analysis of data be expressed in conclusions by the board. Each conclusion reached by the board must be based on facts that were established during the investigation or, lacking factual cause factors, upon the most probable causes and contributory factors.

5-31. PHASE V. The basic directive for aircraft accident reporting procedures requires that the board submit recommendations for corrective action for every conclusion reached regarding cause factors and contributory factors. The effectiveness of these recommendations in the prevention of aircraft accidents is determined largely by the factual data and conclusions on which they are based. It is in this area that the experience and knowledge of the members of the board can be utilized most effectively.

5-32. Each recommendation must be the result of mature deliberation based on factual, or most probable, causes and conclusions. All factors regarding the recommendation must be weighed carefully to insure that the recommendation will be effective in preventing accidents in the future.

5-33. PARALLEL INVESTIGATIONS.

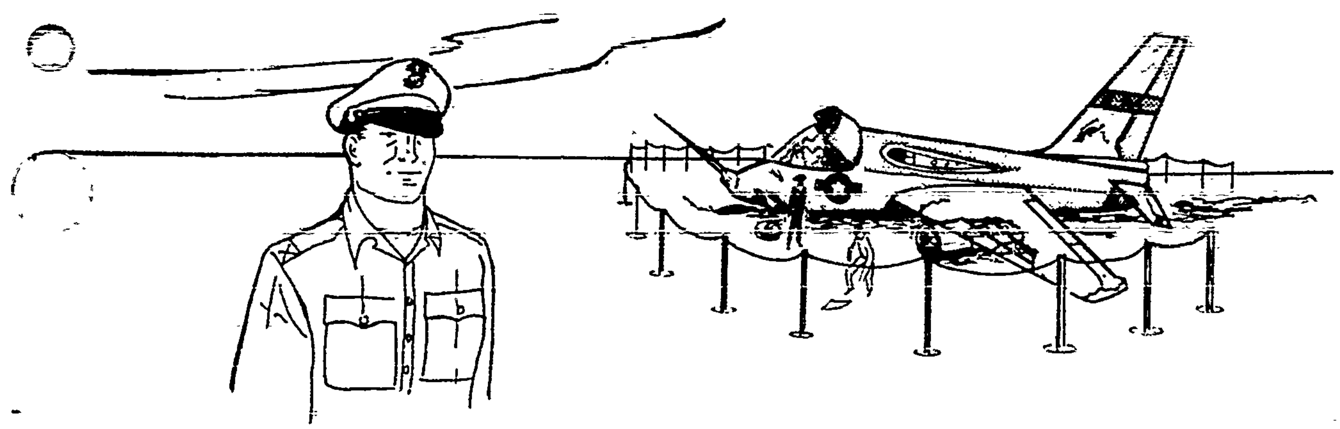
5-34. At the same time the aircraft accident board is conducting its investigation, other agencies of the Department of the Navy and the Federal Government may be conducting investigations of their own. In many cases cooperation among investigators from these agencies can increase the effectiveness of the investigation and ensure that all the relevant facts are uncovered. In order to maintain the privileged status of the investigation conducted pursuant to OPNAVINST 3750.6, which is intended solely for use in accident prevention, cooperation with other investigative bodies is limited in the following areas.

1. Testimonial evidence will be obtained separately. (See Chapter 9.)

2. Deliberations by the various investigative bodies will be conducted independently.

NOTE

Aircraft wreckage will not be released for salvage without concurrence of all investigative bodies.



CHAPTER 6

PROCEDURES AT THE SCENE OF THE ACCIDENT

6-1. INTRODUCTION.

'. The scene of an aircraft accident can read- turn into one of complete confusion unless the investigator is prepared to take quick and decisive action. If certain well-defined procedures are followed, the wreckage and the general area of the accident can be secured and an orderly and thorough investigation can be conducted quickly and efficiently. Disorder will result and time will be wasted if the investigator is at a loss on how to begin or does not understand what priority to give his various duties. This chapter presents a general blueprint of procedures to follow at the accident scene and in conducting a preliminary investigation of the accident.

6-3. OFFICER-IN-CHARGE.

6-4. Current OPNAV instructions specify that surviving crew members (if physically able to so) or the first military personnel arriving at the scene of the accident will take charge until relieved by proper authority.

5. In many cases, it may be possible for members of the aircraft board to accompany the crash rescue party to the accident scene rather than travel with the convoy that follows. The senior member of the board then present at the scene should determine who is in charge. Unless a responsible and competent officer is in charge, the senior board member present should take command immediately. He should coordinate the activities of rescue personnel, investigators, medical personnel, salvage crew, civil authorities, and other persons appearing at the accident scene.

6-6. SAFETY OF PERSONNEL.

6-7. Safety of personnel involved is of primary concern in every aircraft accident. The officer-in-charge at the accident scene will insure that all occupants of the aircraft are removed from the wreckage as expeditiously and safely as possible, using the most effective means of rescue available.

6-8. Immediate steps must be taken to prevent injury to personnel from fire, explosion of fuel, cook-off of armament, ejection seat and canopy charges, and other explosives, and other hazards present at the accident scene. The most effective means of providing security in these cases is to rope off and place guards around the scene at a distance from the wreckage sufficient to insure protection for personnel in case of explosion and resultant flying debris.

6-9. OTHER IMMEDIATE DUTIES.

6-10. There are several details that require immediate attention at the scene of the accident after the requirements for personnel safety have been met. These details include:

1. If the flight surgeon or medical member of the accident board is not present, obtain the necessary medical services, not only for the purpose of treatment and disposition of the injured but also for the purpose of isolating factual information on human failure.

2. Secure the wreckage against the hazards of fire and further damage.

WARNING

Operational jet aircraft are equipped with ejection seats that contain high-explosive charges. The seat catapult charges, automatic lap belt releases, some bomb racks, and pyrotechnic parachute openers should never be disturbed or tampered with until they have been examined, disarmed, and declared safe by qualified armament/EOD personnel.

3. Insure that the wreckage is not tampered with except to rescue its occupants or to secure it against fire and explosion.

4. Check the guard detail to see that members are posted properly and understand their duties. If the military guard called for in the pre-accident plan has not arrived, set up a temporary guard using unengaged military personnel, civil authorities, or other cooperative citizens. Be certain that they understand their duties in restraining the curious, souvenir hunters and scavengers, and others who might damage or remove evidence and interfere with the investigation.

5. Locate all available witnesses at the accident scene immediately and record their names and addresses. This is one of the most important steps in the investigation. Evaluation of the witnesses' statements is often helpful in identifying the areas on which the investigation should be concentrated. Locating and questioning of witnesses should be accomplished as indicated in Chapter 9.

6. Supervise the work of the photographer to obtain aerial and ground views of the accident scene (see Appendix C.)

7. Insure that the message reports of the accident are transmitted by the reporting custodian or the nearest military base commander in accordance with current OPNAV instructions.

8. Estimate the number of men and any special equipment that will be needed in recovering the wreckage.

9. Maintain positive military control over the wreckage recovery crew to insure that wreckage recovery operations do not begin until the senior member of the accident board releases the wreckage for recovery.

6-11. PRESS RELATIONS.

6-12. If the pre-accident plan does not function properly and the public information officer is not able to be present immediately, the officer-in-charge will have to conduct press relations at the accident scene. The investigator who is unfamiliar with this task and has little understanding of the several techniques used by news reporters to gather information should be aware of the following.

1. No attempt should be made to tell the reporter what he should write in his story or to restrict him from interviewing civilian witnesses. Military personnel should be cautioned against making statements, expressing opinions, or giving out information concerning the accident.

2. The reporter has been assigned by his superiors to write a story about the aircraft accident and he is going to write one regardless of what is said to him. A few moments of calm conversation with the reporter can usually prevent a great deal of misunderstanding. In most cases newsmen will understand the truth of the statement that the accident investigation has just begun and that it is impossible to make statements with incomplete information. Without giving the appearance of trying to conceal anything or pass the reporter's questions off lightly, the investigator should advise him that the station and unit PIO's will have statements as soon as the exact events leading up to the crash are known. The release of information on military aircraft accidents to the news media is governed by regulations. These regulations specify who will issue news releases. Accident investigators are not among persons so authorized, but it usually will help press relations at an accident scene if they do not quote these regulations as the reason why they cannot fill reporters in completely on the accident details. It should be remembered that the reporter would have a much better story from a news standpoint if he were restrained or treated arbitrarily by the military than he would have from the aircraft accident alone.

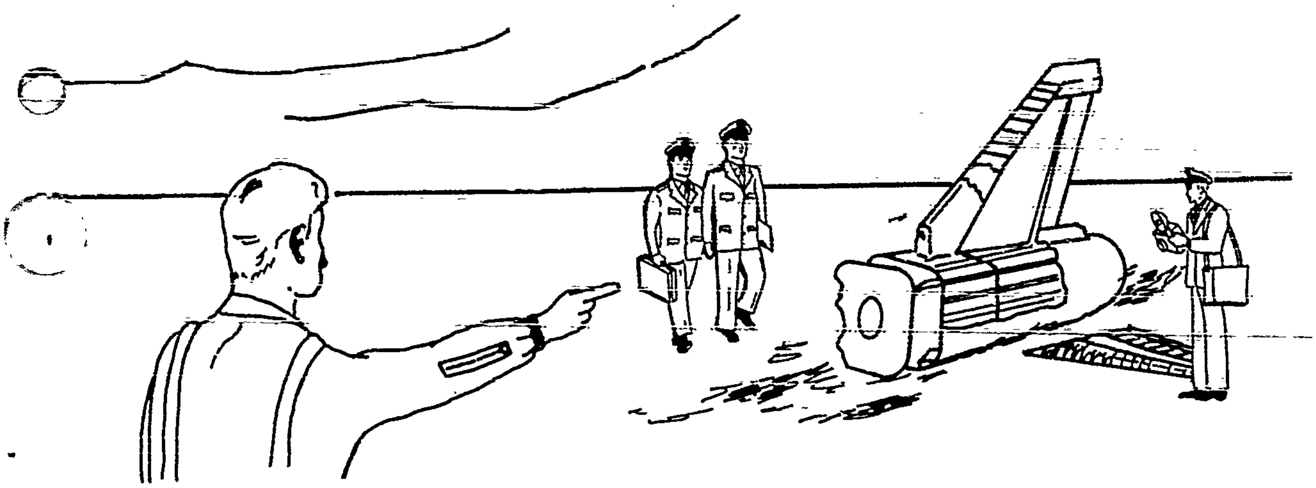
3. In many instances the news reporters are able to provide a great deal more information than they receive from the investigators. Often reporters are among the first persons to arrive at the accident scene and may have talked to several witnesses before the crash-rescue party arrives. This fact may not be apparent from their conversations, which probably will consist primarily of questions. In the great majority of cases the reporter will be happy to pass his information along and give the investigator further assistance in lo-

Figure 6-1. The Senior Member Briefs the Board [illegible] at Accident Scene

cating witnesses if he understands the value of this effort to the aviation safety program.

4. When an accident occurs on nonmilitary property, the press should be allowed complete freedom in taking pictures, consistent with safety procedures, unless classified material is involved. The photographer should be advised of the classified nature of the equipment, and it should be either covered or removed before photographs are taken. Although no restriction is placed on the photographer, a tactful request will usually prevent his use of gruesome photos.

5. Senior members should insure that their boards are thoroughly briefed on press relations.



CHAPTER 7

PRELIMINARY INVESTIGATION

7-1. GENERAL.

All members of the accident board should go to the scene of the accident. After the required immediate action has been taken, a preliminary investigation should be conducted with the complete accident board participating. The members should remain together during this phase of the investigation and the senior member should supervise the operation. The purpose of this preliminary investigation is to familiarize the board with the primary areas of the investigation, general aspects of the accident, and salient details of the wreckage.

7-3. The results of the preliminary investigation will determine the general type and extent of the main investigation and will provide the senior member of the board with information on which to base requirements for task groups.

WRECKAGE ANALYSIS AT THE SCENE. examination of the physical evidence at the scene of an accident should begin with an analysis of the wreckage and the surrounding terrain to determine how the aircraft crashed. This should be followed by a detailed inspection of all of the wreckage to determine causal factors such as material failure, malfunction of the engines or of any systems. The examination of the surrounding terrain, all objects struck by the aircraft, correlation of witnesses' statements, and other evidence will indicate the approximate flight path of the aircraft immediately prior to impact (see figure 7-1). A study of the impact damage to the aircraft and the distribution of the wreckage will suggest the approximate attitude at the time of impact. The angle of impact and attitude, plus the wreckage pattern, will indicate the type of accident. (See Appendix B for general procedures for analyzing the physical evidence at the accident scene.)

7-5. WRECKAGE PATTERN. A listing of some of the more frequently found wreckage patterns is provided below. These are the most easily identified types, but they do not represent all cases. Each accident must be analyzed on the basis of the wreckage distribution found at the scene. Most wreckage patterns will fall somewhere between these typical patterns, or may be a combination of two or more.

1. Dives Into the Ground. Dives into the ground at high speed are usually characterized by wreckage confined to a circular area around a deep ground scar. In such cases, the aircraft and

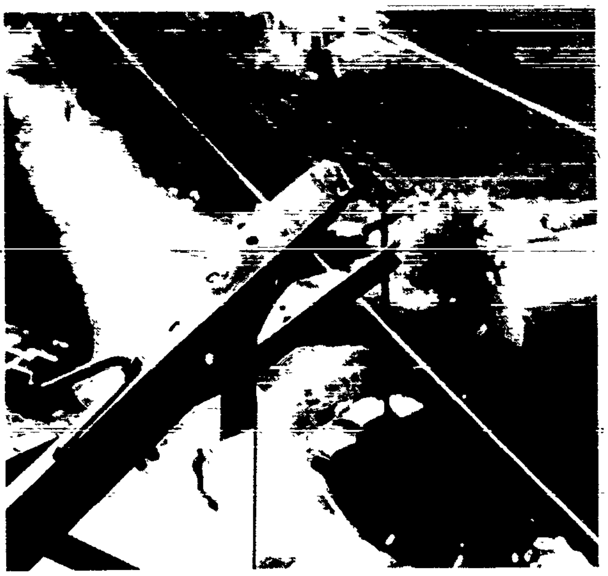


Figure 7-1. Power Line Tower Struck by Aircraft Resulting in Accident Shown in Figure 4-1

engine(s) will probably be completely demolished. Parts of the wing structure and empennage may be found near the edge of the crater and the engine(s) will probably be at the bottom. In many cases of jet fighter aircraft, these craters have been found to extend to a depth of 30 or 40 feet. Excavating to recover all parts of the aircraft for detailed examination in these cases is a difficult problem. The novice investigator is prone to let himself become discouraged the first time he sees a typical "hole-in-the-ground" at the scene of a jet aircraft accident. He must remember that perseverance and patience must be the order of the day and that the cause of an accident is often found after digging out every part.

2. Spins. The easiest pattern to identify is that left by an aircraft spinning upon impact. Spin accidents will leave a small concentrated pattern with the depth of the scar dependent on the type of aircraft and its speed upon impact. Indications of rotation will be found on the ground adjacent to the scar. One wing (toward the inside of the spin) will have taken most of the impact. The outside wing will show less impact damage and will probably be thrown forward. The fuselage will usually be broken in several places and the empennage will be thrown forward in the direction of spin rotation.

3. Low-Level Flight. When the wreckage is found in a long, narrow distribution pattern, particularly on flat terrain, it indicates a flat approach. This evidence suggests an attempted forced landing, instrument flight at insufficient altitude, or buzzing. High speed, which is indicated by the engine and other heavy parts having progressed further along the ground path of the wreckage, is a characteristic of low-level flight patterns. In the case of reciprocating-engine-driven aircraft, typical "prop bites" may be found which will enable the investigator to compute the approximate speed of the aircraft.

4. Loss of Control. Loss of control in the air usually terminates in a spiral. This is particularly true during instrument flight. When the aircraft strikes the ground in a spiral it is usually in a nose-down attitude with a high degree of bank. This will be identified, in most cases, by collapse of one wing with corresponding ground scars followed by cartwheeling and extensive impact damage.

7-6. DOCUMENTATION OF WRECKAGE. It is essential that the wreckage be thoroughly documented during the preliminary investigation. Once the wreckage has been moved the photographs and diagrams made on arrival at the accident location constitute the only means of reconstructing the scene of the accident. Any omissions in these records may result in the loss of an important clue to the cause of the accident. The following guidelines should form a basis for documentation of the wreckage.

1. Establish the extreme limits of distribution of wreckage.

2. Attempt to account for all extremities and control surfaces to determine whether structural failure occurred in flight.

3. Prepare a preliminary wreckage diagram while making notes on the ground scar, aircraft impact angle, and location of the main parts of the wreckage. This information must be recorded as soon as possible because the wreckage may be moved in spite of all attempts to protect it. (See Appendix D for details of wreckage diagram preparation.)

4. Make a photographic record of the accident scene using as many pictures as required to fully document the wreckage. (See Appendix C.)

7-7. AEROMEDICAL CONSIDERATIONS. Aeromedical considerations should be investigated as indicated in Chapter 11.

7-8. WRECKAGE RECOVERY.

7-9. The problem of recovery of aircraft wreckage can be divided into two different categories, namely the recovery of wreckage on land and the recovery of wreckage underwater. Of course, there are variations in each of these categories when accidents occur in swamps, mountains, etc. (see figure 7-2). Generally, the two principal categories have definite recovery methods which will insure that all available parts are recovered. Except in special circumstances, wreckage must not be moved until released by the senior member of the accident board.

7-10. RECOVERY OF WRECKAGE ON LAND. Recovery of wreckage on land is often a laborious task. After wreckage distribution diagrams, preliminary inspections, photos, etc., have been made, the following steps should be accomplished.

1. Have a search party of from 20 to 40 men, if that number is available, carefully pick up each part. This work party should be composed of the best qualified men available, properly equipped with suitable work clothing, cardboard

Figure 7-2. Recovery of Wreckage is Often a Laborious Task

boxes, and gloves. The working party should be instructed to pick up all parts. Do not let any member of the working party make decisions as to which parts to pick up, this is a problem for the accident investigator. The working party must be instructed to handle each piece of wreckage carefully to preserve evidence.

2. Search back along the flight path for any parts that may have separated from the aircraft before it crashed.

3. Care must be exercised to see that all damage is cataloged before the wreckage is moved in order to differentiate between recovery crew damage and crash damage. Members of the accident board should supervise the movement of the wreckage in order to prevent unnecessary damage by the recovery personnel.

4. A complete investigation may necessitate that components such as engines or parts of the airframe be shipped to a depot maintenance facility for detailed analysis. Extreme care must be exercised in removing the assemblies. Wreckage recovery is the responsibility of the closest naval air station, whose equipment may be augmented by local agencies. The nearest Air Force, Army, National Guard, Reserve Activity, National Park Service, county agent, or local contractors can be solicited for assistance; however, if civilian sources are requested, payment for services received must be arranged through the chain of command.

7-11. RECOVERY OF WRECKAGE UNDERWATER. (See figure 7-3.) When aircraft wreckage is underwater, the problems of location and recovery assume major proportions. Special facilities are available which may mean the difference between success and failure. The following steps will aid in investigations involving underwater wreckage.

1. Location of the wreckage is the first problem. This may be accomplished by carefully plotting the location described by witnesses. Another method is to look for oil bubbles, which often continue to escape even days after an accident. A third method is by dragging or sweeping the area using minesweeping equipment, sonar, MAD gear, underwater TV or photography, or manned submersibles. Minesweeping activities have special equipment which is designed for the location of objects underwater. Station pre-accident plans should contain information on how to obtain services of divers, minesweepers, MAD gear, submersibles, and clamshell cranes and other weight-lifting equipment. When the proper assets are not locally available or their use infeasible due to circumstances, assistance should be requested of the Controlling Custodian via the Immediate Superior in Command, who will normally pass the request to the Supervisor of Salvage as required by current OPNAV instructions. SUPSALV maintains a cadre of experts who are available to travel to the scene and coordinate search and recovery operations.

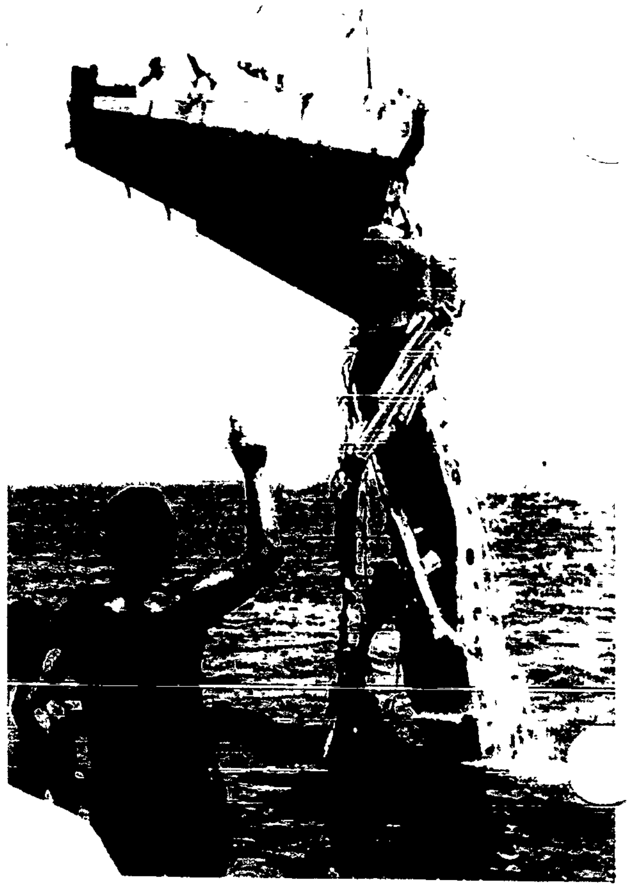


Figure 7-3. Recovery of Wreckage Underwater

2. After the wreckage has been located, the divers should try to sketch the location of identifiable parts. The divers and other recovery personnel may not have aviation experience and the investigators should extend all assistance and guidance possible.

3. During the recovery operations a member of the accident board must be available to supervise, answer technical questions, obtain photographs, and categorize damage inflicted during recovery operations. A proper record of damage sustained during wreckage recovery will eliminate confusion in future analysis. The wreckage should be flushed with fresh water and given a light oil spray to reduce the effects of salt water corrosion. Parts to be disassembled should be placed with the inspection agency as soon as possible to reduce the effects of corrosion to a minimum.

7-12. PRESERVATION OF WRECKAGE.

7-13. Following an aircraft accident the wreckage should not be moved or disturbed for a period of 24 hours unless the wreckage interferes directly with vital civil functions or essential military operations (see figure 7-4). In case of bona fide interference, the commanding officer of the base or unit concerned is authorized to direct the removal of the wreckage from the scene of the mishap to the salvage yard or to an area where there is no interference.

7-14. When the wreckage is removed prior to the investigation by the aircraft accident board, it is the responsibility of the officer ordering such removal to have an accurate plot of the wreckage distribution prepared. A photographic record of the scene of the mishap and of the wreckage, including any known material failures, must also be made before the wreckage is moved.

7-15. In moving the wreckage in these cases every effort must be made to prevent further damage. A record of any damage to the wreckage during rescue or recovery must be maintained.

7-16. The 24-hour period specified herein is necessary to allow time for other agencies of the Department of the Navy to receive dispatch notification of the mishap and make a decision relative to their interest in conducting an independent investigation.

7-17. The senior member of the aircraft accident board is authorized to release the wreckage for recovery on completion of the investigation at the scene of the accident. In cases where independent investigations are being conducted by other agencies of the Department of the Navy concurrently with the aircraft accident board investigation, the senior member of the board must not release the wreckage for recovery until the senior members of the various independent investigating teams announce the completion of their investigations at the scene.

7-18. Parts suspected of failure, mechanical trouble, or inherent faulty design must be wrapped in cloth or boxed to prevent loss or further damage. They should be carefully tagged to identify them in relation to the accident (place, date, and bureau number) and in respect to their location in the aircraft or at the accident scene. The tag should also contain a brief statement on the suspected relationship of the part to the causes of the accident so that proper tests may be made on such parts. Examples of parts to be tested and preserved as described above are:

1. Landing gear parts suspected of improper heat treatment.

2. Fittings that seem faulty in design or workmanship.

3. Ruptured plumbing or fittings.

4. Plumbing not properly supported, subject to excessive vibration, or improperly annealed.

5. Faulty or suspected wiring, electrical, or radio equipment.

6. Faulty or suspected instruments, auto pilots, etc.

7. Defective engines, propellers, or ac-

cessories, such as carburetors, governors, superchargers, or supercharger controls, fuel control assemblies, constant speed drives, or ignition systems.

7-19. In many cases of engine failure or suspected engine failure, it will be desirable to obtain specimens of fuel or oil for laboratory analysis. Such samples will be preserved in clean containers (one-gallon cans) and identified as suggested above. Give the location at which the specimen was obtained. Fuel and oil samples will be analyzed by the laboratory for quality and for the presence of foreign matter, as conditions dictate. Foreign matter found in fuel and oil strainers should be preserved and analyzed by the laboratory in every instance where it seems advisable.

7-20. FIRE DAMAGE.

7-21. The investigator must attempt to determine whether fire preceded the crash. Witnesses often state that they observed the aircraft on fire prior to impact. The investigator should be most careful in correlating these statements with the evidence revealed by examination of the wreckage. Once it is established that the fire occurred prior

Figure 7-4 Preservation of Wreckage by Use of Inflated Building

to impact, the investigator must attempt to locate the origin of the fire and determine how it caused the accident. The source of the fire may frequently be localized at the point of greatest damage or at a point indicating the greatest amount of heat. A broken fuel or oil line which causes a fire can frequently be located by careful inspection of the damage. Information on a fire in flight is valuable as a guide to corrections in design and to the development of fire-warning and fire-extinguishing systems. Fire frequently occurs following minor accidents. Information concerning how the fire started and how it was fed will assist in developing successful fire-prevention and fire-extinguishing methods.

7-22. DISTINGUISHING FIRE IN FLIGHT FROM FIRE AFTER IMPACT. Fire occurs in a large percentage of major aircraft accidents. An inflight fire can be detected and distinguished from post-impact ground fire by observing the following characteristics.

1. After reassembly of the wreckage, it will be noted that the components around the inflight fire area will be burned more intensely than those burned solely by ground fire.

2. Fires in the air are very severe; they burn through the fuselage and wings, heating large portions of metal into a molten state. Analysis of the direction of the flow of the molten metal deposits also helps in the determination of where the fire is located and if the fire occurred before or after impact. With an inflight fire, molten metal will be deposited on the forward side of rivet heads and other surface irregularities downstream from the location of the fire.

3. Aluminum parts subjected to shock (such as occurs at impact) while in a molten state exhibit a "broomstraw" effect (see figure 7-5.)

4. The smoke pattern of inflight fire follows the slipstream, and there will be clear spaces on the aft side of the rivet heads and skin splices.

5. The smoke pattern of a ground fire is sporadic or in a different direction from that

Figure 7-5. Broomstraw Effect in Aluminum

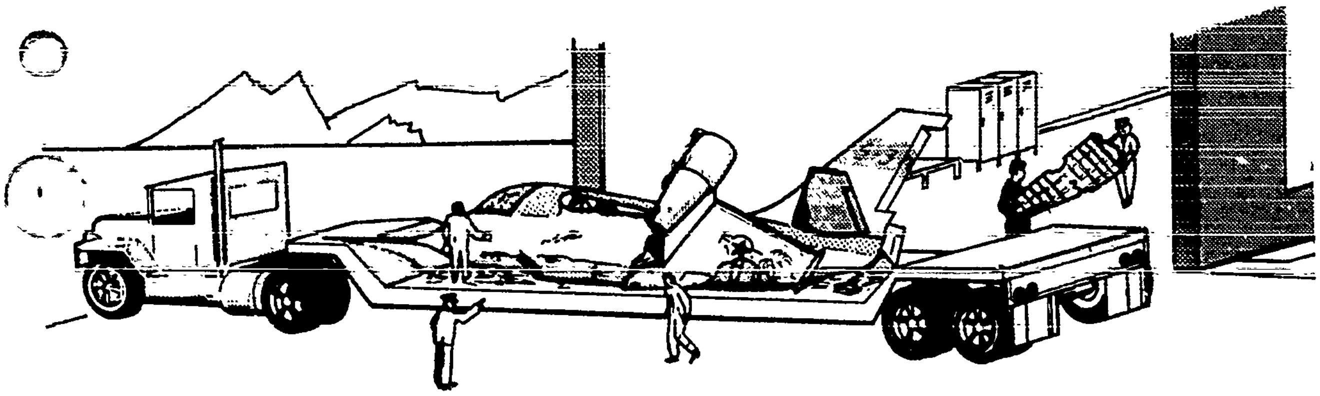
caused by slip-stream. The investigator can establish evidence of fires on the ground by opening crumpled portions of the aircraft which are burned. Under these circumstances the inner folds will be clean and may still retain paint in the original condition. A positive means of identifying ground fire is to match a burned part of the structure with adjacent pieces (see figure 7-6). If any one of these adjacent pieces is clean, the conclu-

Figure 7-6. Comparison of Adjacent Pieces for Fire Damage

sion can then be made that the burned part was due to ground fire.

6. A fair proportion of structural parts subjected to ground fire generally have twigs, leaves, etc., outlined in the soot or smoke deposit.

7-23. Never assume that the causes of an accident cannot be determined because fire has damaged the structure of the aircraft. Fuel, electrical, control, and hydraulic systems may have escaped serious damage. Valve positions can usually be ascertained, and the condition of the fuel and oil tanks will frequently indicate whether or not they contained fluid at the time of the fire. Information as to whether fuel and oil tanks broke, tore, or collapsed in the crash is important. Engines may be seriously damaged externally by fire while internal failure or defects will not be detected without disassembly.



CHAPTER 8

MAIN INVESTIGATION

8-1. INTRODUCTION.

8-2. A thorough and comprehensive study during this phase of the investigation is critical to the success of the aircraft accident investigation since the main investigation will provide the bulk of the physical evidence to be used in the analysis phase. A great deal of information must be assembled before deciding whether a structural failure or malfunction is involved in an aircraft accident. Some of this information must be derived at the scene. Other data can be secured only when the wreckage is laid out in a hangar or other location where it can be closely examined. The detailed examination should be made with two questions in mind. First, did structural failure occur? Second, if structural failure did occur, in what sequence did it happen? Most structural failures in flight have been determined to be caused by overstress. A common cause of overstress is the performance of violent maneuvers or the attaining of high airspeeds while the landing r or flaps are extended.

8-3. It is important to locate as many pieces of the aircraft as possible so that the wreckage trail can be determined. Remember that the missing piece of wreckage may hold the clue which will answer the question of which part failed first. Preparation of a detailed wreckage distribution diagram as described in Appendix D will insure that none of these clues are lost.

8-4. The investigator should avoid the temptation to produce an early conclusion. Allow the collection of evidence to proceed logically in an unbiased manner. Be on guard particularly against the influences of other persons who may have made snap judgements of cause factors based on the preliminary evidence revealed by the field work. Remember that the recommendations based on a conclusion that a structural failure is a primary cause factor may result in the redesign or retrofit of the entire aircraft. Wait until your investigation is complete before you come to any decisions.

8-5. AIRCRAFT CONFIGURATION. Of primary interest to the investigator is the configuration of the aircraft at impact. Knowledge of the aircraft configuration enables the investigator to determine the stresses on the aircraft as well as the flight mode at the time of the accident. Examination of landing gear uplatches and the position of the landing gear actuating cylinders will usually reveal the position of the landing gear.

The position of the flaps, leading-edge slats, speed brakes, wing locks, canopy, and tailhook can usually be determined by a similar examination. The detailed study of these parts is greatly facilitated by the use of operational mock-up trainers (see figure 8-1). Units such as the Naval Air Maintenance Training Detachments and operational flight trainers allow detailed observation of aircraft systems as they are sent through their operational cycles. Comparison of an actuator from the aircraft and an actuator in a mock-up will generally reveal the position of the control surface quite accurately.

8-6. EXAMINATION OF BREAKS AND FAILURES. Those parts which were found farthest from the main wreckage should be carefully examined first, as their location might indicate that they failed first. Examine each break individually to determine which occurred at impact and which in flight. The breaks that occurred in flight should be examined with a powerful magnifying glass for evidence of metal fatigue. This procedure should be continued until every break of every part of the airframe structure has been identified as either inflight or impact breakage. Do not overlook any part, no matter how seemingly insignificant. A failure of a small bolt can lead to failure or malfunction of vital aircraft parts or systems.

8-7. The position of a part of the aircraft in relation to the main wreckage can often be used to distinguish inflight from impact failures. Gen-

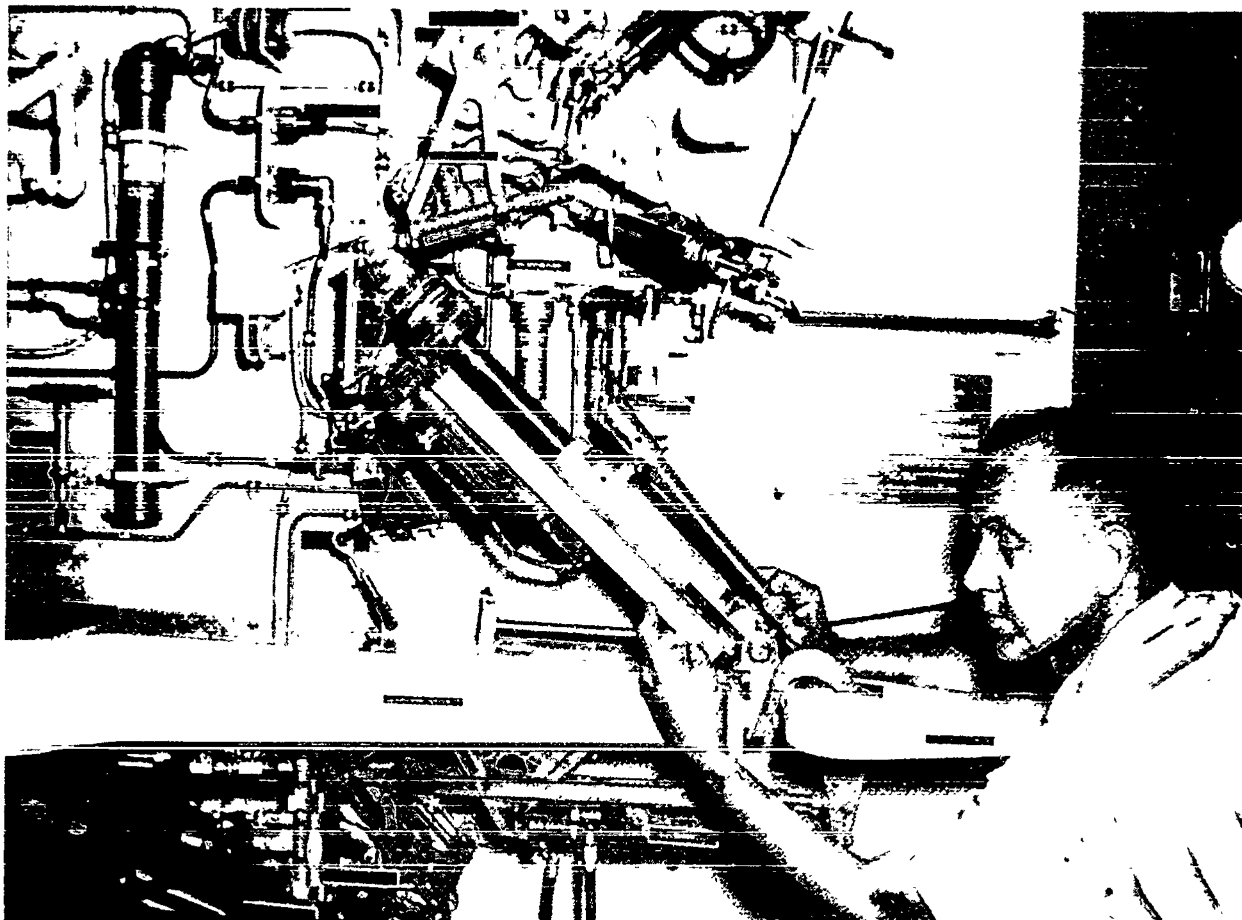


Figure 8-1. Operating Mockup of Flight Control System

erally, if both wingtips are found at the scene of the accident, it may be assumed that both wings were on the aircraft at impact. Likewise, if the nose section and the empennage are at the scene, it may be assumed that the fuselage was intact. Presence of the engines at the scene will clearly indicate that they did not leave the aircraft prior to impact. Landing gear components, canopies, and ejection seats should be located. Their position relative to the main wreckage may be significant in determining the type of accident and the direction of the investigation.

8-8. DETAILED EXAMINATION. The selection of a suitable place to work, and the assurance that it will be available and well guarded, is essential in this phase of the investigation. This area should be restricted and only those personnel directly connected allowed entrance. Every precaution must be taken against disturbing the wreckage or inflicting additional damage to it. When the wreckage arrives at the working area, the investigator should first divide it, as far as identification of parts permits, into separate sections as follows:

1. Fuselage
2. Wings (each wing separately)
3. Empennage
4. Control surfaces
5. Landing gear
6. Cockpit
7. Instruments
8. Radio and radar
9. Powerplant
10. Fuel system components (including tanks)
11. Hydraulic system components
12. Electrical system components
13. Emergency equipment (ejection seats, canopy, etc.)

8-9. AIRFRAME FAILURES.

8-10. Airframe failures occur in a fairly large percentage of aircraft accidents. Components that are a part of the airframe group, in relative order of frequency of failure, are: wings, tail surfaces, control surfaces, fuselage, landing gear, and trim tabs.

8-11. RECONSTRUCTION OF AIRFRAME. Reconstruction of the entire airframe structure or significant portions thereof may be necessary to determine the sequence of failure. The problem of reconstructing is essentially that of solving a three-dimensional jigsaw puzzle in which the individual pieces have been somewhat distorted. It is here that the manufacturer's technical representative and all other available people with knowledge of the aircraft can be used to advantage in identifying parts. In addition, parts may be identified by their construction, color, type of rivets, matching insignia, or other paint on them. This tentative identification can be checked by matching the fractures against adjacent pieces. The actual reconstruction can be accomplished by using trestles and racks, supporting parts from the ceiling by wires or cables, or by constructing a "chicken wire" mock-up and attaching the parts to it (see figure 8-2). It is here that the ingenuity of the investigator will be called upon to devise reconstruction techniques for solving this problem.

8-12. When the parts are properly aligned on the mock-up, it may be readily apparent that skin wrinkles on one piece are continued on another, indicating that the wrinkles were almost certainly present before the two pieces were separated. Smears, scores, tears, paint scrapes, etc., can also be used to determine origins and sequence of failures. Good reconstruction will also reveal the manner in which components struck each other during disintegration.

8-13. Position of control surfaces at the time of impact is also important in evaluating the stresses which may have been placed on the structure of

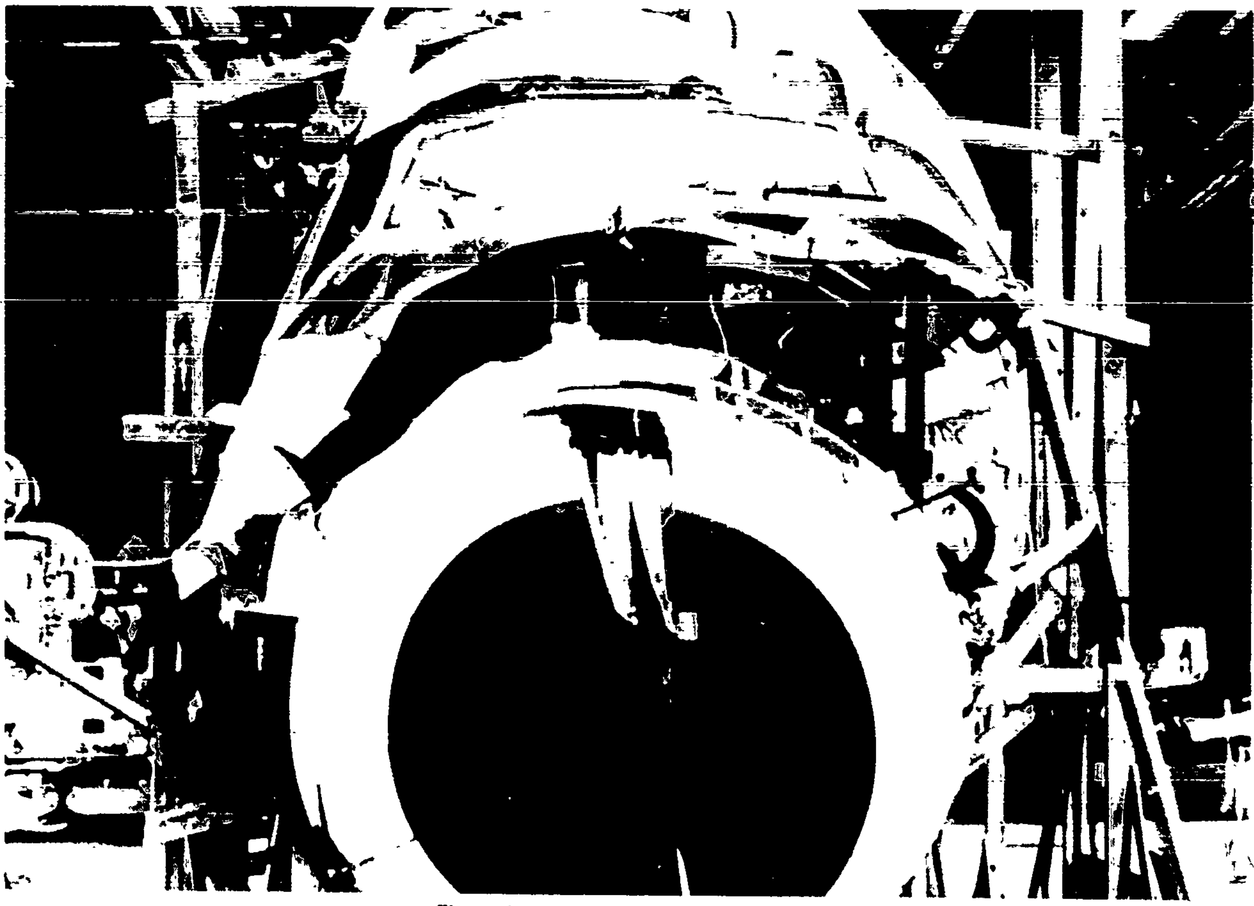


Figure 8-2. Airframe Reconstruction

the aircraft. The position at time of impact can be determined by counting the extended threads on the jackscrew or the position of the actuator and noting the control surface position on a sister aircraft or mock-up when the jackscrew or actuator is in the same position.

8-14. Cockpit.

WARNING

Jet aircraft are equipped with ejection seats that incorporate explosive charges. Before entering or working near the cockpit, insure that the seats are disarmed or safety pins are inserted by qualified personnel. Under no circumstances should an investigator approach an ejection seat when visual evidence indicates that the pilot attempted to eject.

8-15. The cockpit should be thoroughly checked for evidence of fire, smoke, electrical arcing and attempted ejection by the crew. The positions and readings of all switches and instruments should be noted, and, whenever possible, documented photographically. Switch positions and instrument readings are correlated with known aircraft and flight conditions during the analysis phase of the investigation. Remove any instruments, radios, or gauges suspected of failure for operational checks.

8-16. POWERPLANT FAILURE.

8-17. Powerplant failures or malfunctions are frequently cause factors in aircraft accidents. For this reason, it is essential that a careful examination of the powerplant and its associated components be made to determine whether they are involved as cause factors. It is especially important to include a negative statement in the report regarding the powerplant if it is determined that failure or malfunction is not involved. In most cases a complete teardown of either a gas turbine or reciprocating engine will not be possible at the scene of the accident or at the facility conducting the investigation. Arrangements should be made to ship the engine(s) involved when failure or malfunction is indicated, to the appropriate rework facility for a safety engineering investigation as soon as the investigator has learned all he can from his examination. The completely equipped rework facility will be able to confirm or refute the findings of the investigator and this information can then be submitted as a supplement to the report. Requests for safety engineering investigations will be made by message to the cognizant systems command agency in accordance with current NAVAIR instructions to determine the appropriate Naval Air Rework Facility and shipping instructions.

18. Whenever possible, a member of the accident board should arrange to witness the disassembly of components submitted for examination. When this is not possible, it is extremely important to furnish the rework facility with sufficient background information concerning the accident to enable them to evaluate intelligently any evidence disclosed by disassembly. Engine failures caused by internal malfunction are usually the easiest for competent personnel to recognize because the evidence ordinarily is not affected by impact damage.

8-19. There are two general categories of aircraft engines: gas turbine engines and reciprocating engines. Characteristic failures and investigative techniques for each type of engine are discussed in the following sections.

20. GAS TURBINE ENGINES.

8-21. The vast majority of present naval aircraft are powered by gas turbine engines. The class of gas turbine engines includes turbojet, turbofan, turboprop, and turboshaft engines. All are driven by a gas turbine and differ primarily in the method in which they produce usable power. Therefore, many of the characteristics for turbojet engines described in the following section will also apply to turbofan, turboprop, and turboshaft engines.

8-22. TURBOJET ENGINES.

8-23. There are two basic types of turbojet engines, namely, the axial and centrifugal-flow types. The axial-flow turbojet is the powerplant most commonly used in naval aircraft. Axial-flow engines can be broken down into three main types: single-rotor engines, which are generally limited to subsonic speeds; dual-rotor or twin-spool engines, which can be operated over a wider range of Mach numbers; and single-rotor engines with variable angle inlet guide vanes and stator blades in the compressor section and variable exhaust nozzles, which are another type of high-performance powerplant that can operate well into the supersonic speed range.

8-24. Basic analysis of engine malfunction may vary slightly for these various types. The investigator should be aware, however, of two primary characteristics common to all turbojets. They operate at extremely high temperatures and under heavy centrifugal loads. These two factors should always be taken into consideration when examining an engine.

8-25. POWER ESTIMATION. It is important to determine as accurately as possible the amount of thrust each engine was producing at the time of a crash. If evidence is found that indicates an engine was turning at a high rpm, operating at normal temperatures with normal fuel flow, and the primary airflow was not blocked by some mechanical failure, then the engine should have been producing a high level of thrust. Methods of estimating the rotational speed and the operating temperature for damaged jet engines are discussed below. Fuel flow can be determined from the positions of the fuel valves, the condition of fuel lines and fuel filters, and the quantity of fuel on board at the time of impact.

8-26. DETERMINATION OF ENGINE RPM.

Several indications that will assist in determining rpm at time of impact will usually be found in axial-flow engines. No single one is all conclusive. Several indications are usually required to determine the rpm at time of impact. Even then, it is improbable that rpm can be determined more accurately than a plus or minus ten-percent.

8-27. The investigator should be well aware of the fact that engine breakup and damage is not the sole criterion for establishing rotational speed. Great care must be exercised in separating the damage caused by impact forces from the damage caused by rotational forces. The amount of damage done as the rotational parts come to rest varies as the square of the rpm, so that a small difference in engine speed makes a large difference in the visible damage. While the centrifugal forces on the engine rotating parts vary as the square of the speed, the impact forces do not. The impact forces, however, cause interference and damage that weakens the engine parts so that the total damage to them will indicate a higher rotational speed than actually existed. Soft FOD, such as ice, rags, birds, water, etc., may also present misleading evidence as to actual rpm.

8-28. High RPM. Indications of high engine rpm usually include some of the following:

1. Extensive damage to the compressor rotor blades, with all the blades bent opposite to the dirction of rotation (see figure 8-3).

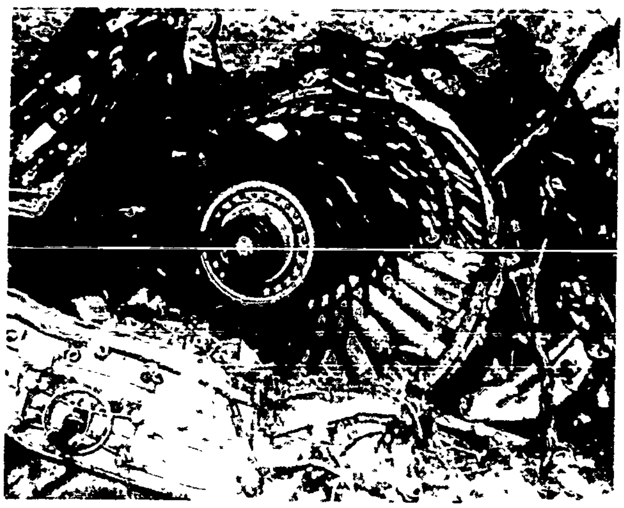


Figure 8-3. Compressor Damage at High RPM

2. Compressor rotor and stator blade interference with heavy scoring of the casing. If blade failure occurs over a period of several seconds, there will be evidence of heavy scoring and peening of the case and blades (see figure 8-4). The compressor case may fail because failed blades jam up at the rear of the compressor. If blade failure is sudden, there will be little evidence of scoring and peening (see figure 8-5).

3. Compressor rotor unstacked and/or turbine shaft sheared. Torsional shearing of the compressor or turbine shaft is usually caused by a sudden stoppage of the rotating parts and most often indicates high engine speeds and large impact angles (angle between horizontal axis of engine and the ground in excess of forty-five degrees) (see figure 8-6).

4. Bending of the turbine rotor blades eighty degrees or more opposite to the direction of rotation. If impact forces are light, the blades will rub the turbine shroud smoothly and give a machining effect. Under high impact forces, the shroud will be torn and gouged.

5. Large amounts of dirt and other foreign matter will be ingested by the engine if it is turning at high rpm and the impact angle is small. The foreign matter sometimes passes completely through the engine, and the compressor and turbine blades usually fail.

8-29. Low RPM. Evidences of low engine rpm are considerably different from those of high rpm (see figure 8-7). They include:

1. Compressor rotor and turbine blades can be bent in both the direction of rotation and opposite to the direction of rotation when impact forces are high and rpm is low (see figure 8-8).

2. Compressor blades torn from their wheels will not be severely battered, nor show signs of heavy peening and scoring.

3. Turbine and compressor blades may be "Z'ed" by impact forces and damage to the blades will not be uniform.

Figure 8-4. Compressor Damage at High RPM

4. Interference marks on the compressor casing will not be smooth and probably will show a chatter effect.

5. There will be little evidence of foreign matter ingestion in the combustion zone and beyond.

6. The shaft between the turbine and compressor wheels probably will be bent by high-impact force when it is turning at low rpm, rather than shearing off as it does under the combination of high impact and rotational loads.

8-30. Twin-Spool Engines. In determining rpm at impact on dual axial compressor or twin-spool engines, the foregoing indications apply. There are two separate compressors, however, each driven by its own two-part turbine. The compressors rotate at different speeds and unusual indications occur that must be carefully evaluated. This is particularly true in the case of shallow impact angles and light impact forces. It is not sufficient to examine the N-1 or low-speed compressor and its associated low-speed turbine. The N-2 compressor and turbine may reveal entirely different evidence. It is necessary, therefore, to examine both compressors and turbines and correlate

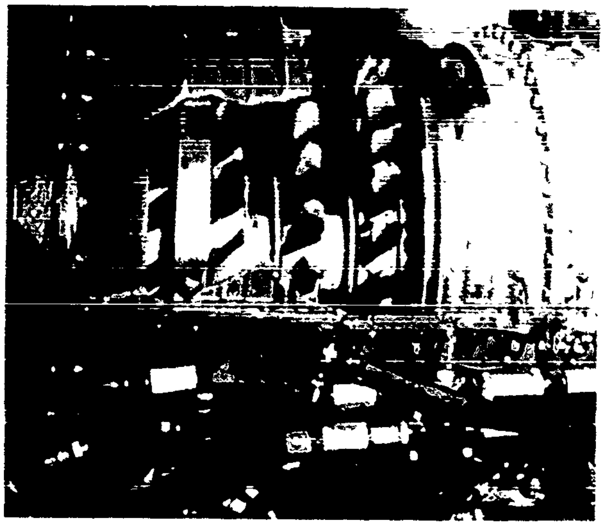


Figure 8-5. Compressor Casing Failure

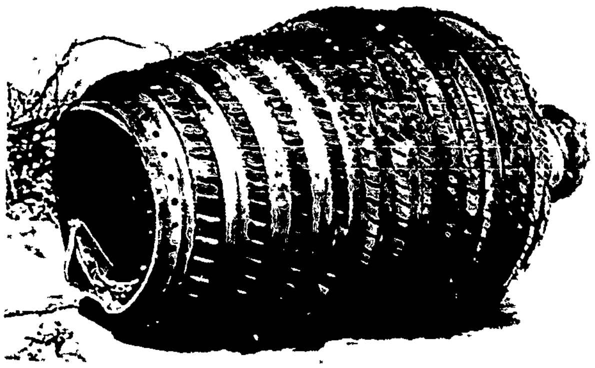


Figure 8-6. Compressor Damage at High RPM

the evidence of rotational damage with impact angle and case distortion. Impact forces should be carefully evaluated because the amount of interference caused by case distortion at impact will determine the amount of rotational damage and the abruptness of stoppage that will occur at any given engine speed.

8-31. Variable Angle Inlet Guide Vanes and Stator Blades and Variable Exhaust Nozzles. Engines employing variable angle inlet guide vanes and stator blades and variable exhaust nozzles exhibit the same characteristics as the single-rotor engine for purposes of rpm determination. However, the rpm of the engine is not the only factor in controlling airflow through these engines. The angle of attack of the inlet guide vanes and stator blades must be considered in order to estimate

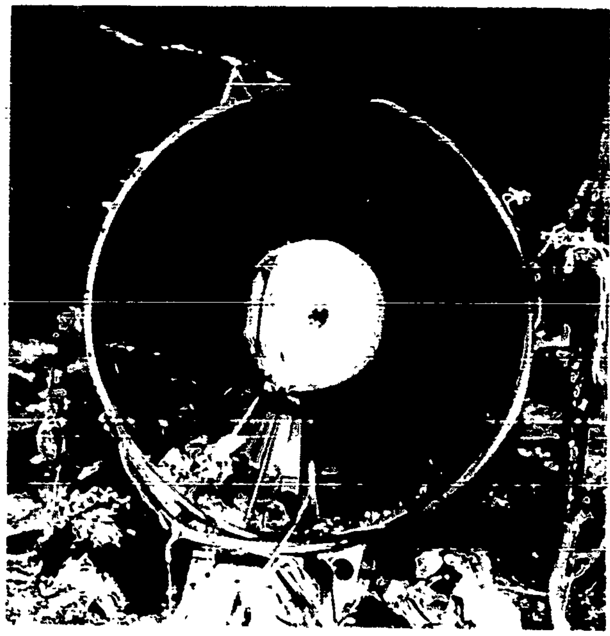


Figure 8-7. Fan Damage at High Compressor RPM

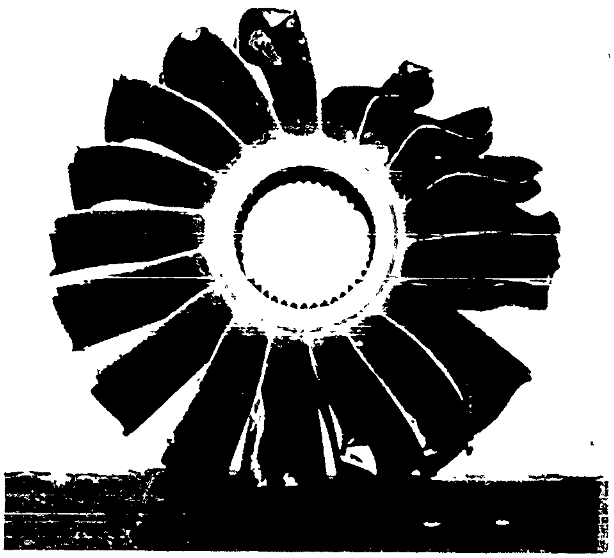


Figure 8-8. Air Conditioning Turbine Damage at Low RPM

the amount of airflow. These angles can be found by radiophotographing or measuring the blade actuators.

1. Impact marks on the compressor shroud left by variable inlet guide vane tips will sometimes give the angle of attack of the blades

at impact which, in turn, can be converted to a specific engine rpm.

2. Depending on the manufacturer, some fuel controls will retain the fuel flow setting being called for at impact.

3. Measuring the variable exhaust nozzle actuating cylinder rod extension will give the nozzle position and possible rpm range.

8-32. DETERMINATION OF ENGINE TEMPERATURE. Fused metal on the hot parts of the engine is the most important clue the investigator has in estimating the engine operating temperature at the moment of failure or impact. The pattern or degree of metal fusion in the engine will often aid in determining the sequence of events that preceded an accident.

8-33. When molten metal strikes a hot metal surface, either fusion or adhesion will result. If the temperature of the metal surface is above the melting point of the molten metal (see Appendix J), fusion will occur, and the metal will be deposited in a smooth, even layer with the appearance of being painted on (see figure 8-9). If the metal surface is cooler than the melting point of the molten metal, adhesion will occur, and the metal will be deposited in globules which have a stucco-like appearance and can be scraped off (see figure 8-10). In aircraft engines, metal fusion usually occurs when small bits of aluminum are scraped from the compressor case and pass back through the engine. These particles normally will stick and fuse to the combustion chamber liners, transition liner, turbine nozzle, turbine buckets, exhaust cones, and exhaust nozzle.

8-34. If the engine is operating at idling rpm or above when the particles of aluminum, or a metal with similar melting point, pass through the en-

Figure 8-9. Metal Fusion on Turbine Blades

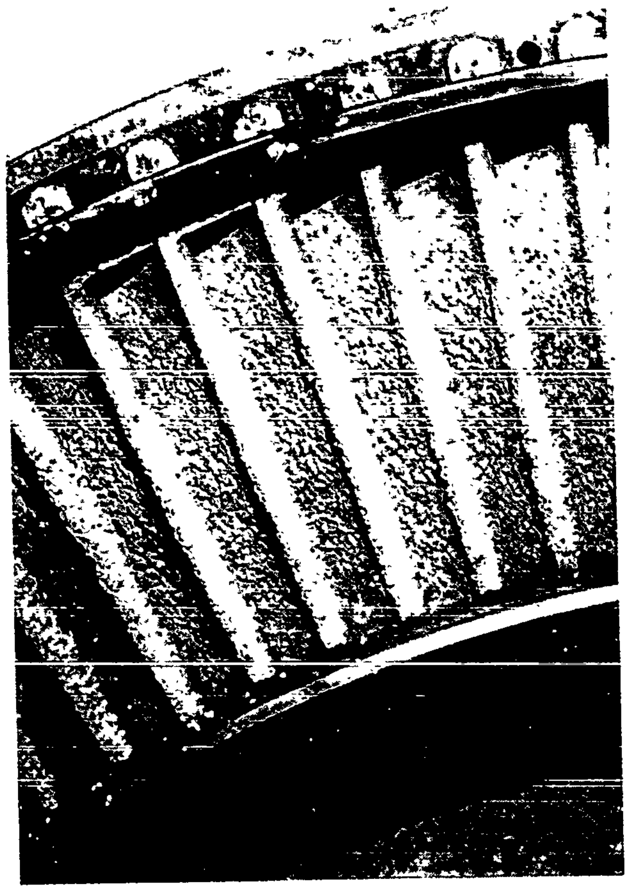


Figure 8-10. Metal Adhesion on Turbine Blades

gine, a smooth, even fusion layer will be deposited on the hot parts. If the engine rotating assembly is decelerating because of an interruption of fuel flow or other malfunction, then the hot parts will be cooling and the fusion will not be complete. The metal particles will adhere in globules that can be scraped off. No metal fusion will occur if the engine flames out or is shut down before compressor damage or duct damage occurs. When fuel flow stops at high speed, the hot parts cool rapidly. The combustion chamber section will stay above the melting temperature of aluminum for four seconds or less. The heavier turbine blades will remain hot enough to fuse aluminum for about ten seconds.

8-35. Many patterns of fused metal will appear in damaged engines. The following common situations will aid the investigator in interpreting these patterns:

1. Normally, inflight compressor failure will result in large amounts of evenly distributed fused material. If the compressor casing fails, however, the amount of fused metal will be greatly reduced because material escapes through the ruptured casing.

2. If a compressor stall occurs, pressure reversals will prevent some of the metal particles from passing through the engine and the amount of fusion will be reduced. Compressor stalls normally will accompany any compressor section failure when operating at low forward speeds and with afterburner.

3. Metal fusion usually will outline the position of the nozzle at the moment of failure. This information is useful in determining the exact power setting.

4. If the exhaust pipe is dented, it is possible to determine whether metal fusion occurred before or after impact. If metal is fused on the downstream side of the dent, then engine failure occurred prior to impact.

5. Engine temperature at time of impact can be determined sometimes by the condition of dirt and debris ingested during a low impact angle crash. Wood pulp and dirt may clog the cooling air passages in the combustion chambers. If the wood is charred, it can be from heat in the engine unless there were significant ground fires.

8-36. CAUSES OF ENGINE FAILURE. Inflight failure of a turbojet engine is generally attributable to one or more of the following causes: compressor failure, compressor stall, turbine failure, bearing failure, engine fire, fuel system failure or malfunction, or afterburner malfunction. Mechanical failure of a turbojet engine is generally catastrophic in nature and a concerted effort must be made to locate all of the engine parts in order to accurately determine the cause of the failure.

8-37. Compressor Failure. Axial-flow compressor failure in flight may be ascertained by several positive indications within the engine. The most positive indication is heavy deposits of aluminum fused to the engine hot parts. These deposits originate from the scraping of the compressor case by failed blades. Usually all the stator vanes except the two exit stages will be torn from the mounting rings. The majority of the compressor blades and stator vanes will be broken into small pieces. These pieces flow aft and jam in the area between the outer and inner combustion chambers. The compressor case will usually crack circumferentially and axially but as a rule will not break open.

8-38. Compressor-rotor failure in flight will not cause compressor blades and stator vanes to be exhausted forward of the inlet of the engine. A compressor failure on the ground can cause blades and vanes to be exhausted up to 100 feet in front of the engine inlet. Such casting of the blades is contingent upon the position of the compressor inlet screens. Differentiating between compressor failure in flight and failure that occurs after impact with the ground is seldom difficult. Primarily there will be only light deposits of aluminum alloy on the hot sections of the engine when a compressor failure occurs after impact. The scoring and gouging of the compressor rotor spacer rings, while deep, will be few in number and intermittent around the periphery of the spacer rings. Many compressor vanes and rotor blades may be torn from their mounting slots but will remain in the compressor case.

8-39. There are five known mechanical causes of compressor failure:

1. Foreign object ingestion, which is the most prevalent cause.

2. Compressor spacer rub, which occurs when the compressor case contracts rapidly on flying into a low-temperature zone. The case reacts to a sudden temperature change more quickly than the rotor and, as it contracts, can cause the compressor blades to rub its inner surface. This interference generates heat that expands the steel spacer rings and induces a high stress in them. These rings are almost always the part that fails when compressor rub takes place. Parts of a failed ring knock out a few blades and a chain reaction is triggered. The tips of the stator blades and the compressor ring will be discolored from heat after a compressor rub that results in failure.

3. Compressor disc rim segment failure. This can occur if the seals between the compressor wheels and spacer discs are not installed properly on an axial-flow compressor. This type of failure can be both the cause and an effect of complete compressor section failure. Great care and skill are needed to determine whether compressor failure originated at the disc rim.

4. Compressor blade fatigue failure. This is usually the result of a nick put into the blade by a foreign object or a manufacturing defect which creates a stress concentration and eventually will cause the blade to fail.

5. Compressor rotor shift. This is generally indicative of a thrust bearing failure and results in almost immediate wipeout of the blades and seizure of the rotor.

8-40. Compressor Stall. Compressor stalls are often associated with cold-weather operation. This type of stall occurs when the pressure ratio across the entire compressor or across various stages of the compressor becomes excessive. This results in air recirculation between stages with corresponding loss of compressor effectiveness. Compressor blade stalling is similar to the stalling of the wing airfoil section on an aircraft.

8-41. An axial-flow compressor stall can be induced by allowing too much fuel to enter the combustion system at any given engine speed. This results in a high compressor discharge pressure due to excess combustion; the pressure ratio across the compressor increases, and compressor stall or pulsation results. As airflow across the turbine diminishes, the engine fuel control senses the apparent engine underspeed, the maximum schedule of fuel is injected in an attempt to hold engine speed, and resulting exhaust gas temperature can reach values in excess of limits, requiring removal of the turbine and other hot section parts for over-temperature damage. Compressor stall is most likely to occur during throttle bursts when additional fuel is injected in accelerating the engine. During a stall, the exhaust gas temperature will usually rise rapidly, aircraft vibration can generally be felt, together with an unfamiliar whistling noise or rumble emanating from the engine.

8-42. Basically there are three types of compressor stalls.

1. Thermal stalls. Thermal stall is used when referring to an engine failure where the nozzle diaphragm and turbine buckets are burned away.

2. Incipient stalls. Incipient stall is a condition where only a few stages of the compressor rotor are in a fluctuating or full-stall condition. This situation occurs during throttle advancement usually in the fifty to eighty percent rpm range. Such a stall causes the engine to "hang up" at fifty to eighty percent rpm and the engine will not accelerate although throttle is in the full open position. Usually stalls of this type will increase the exhaust gas temperature (hot stall) while the temperature will not exceed that which is normal during other cases (cold stall). Incipient stalls are practically impossible to ascertain from the engine wreckage, as only power is lost and actual physical damage to the engine does not occur. Test bench flowing of the fuel regulator subsequent to the accident will help to determine occurrence of a stall. The regulator set-

ting, to accomplish stall, would have to be on the correct side. Weather conditions with ambient temperature below 50°F increase the probability of compressor stall. Such stalls are extremely rare at higher ambient temperatures.

3. Inherent stalls. Inherent stalls are those manifested in engines of late design wherein the pressure ratio across the compressor is so high that stall must be controlled by mechanical means, i.e., variable angle inlet guide vanes and compressor bleed valves. Again there will be no evidence to assist the investigator in determining if this type of stall has taken place. A test bench flow check of the fuel regulator and determination of the operational condition of the variable angle inlet guide vanes and compressor bleed valves is necessary.

8-43. Turbine Failure. Inflight turbine rotor failures are a cause of major accidents in turbojet engines. Three different modes of failure prevail: bucket failure, broach failure, and turbine disc failure. Causes for such failures are many and will be discussed in the order of their frequency.

1. Turbine bucket fatigue with one or more turbine buckets failing at a point outward from the root platform. Bucket fatigue may be attributed to the length of service life, vibration, irregular fuel nozzle flow patterns, hot starts, overtemperature operation, malfunctioning fuel controls, foreign object damage, and improper metal heats and forging (see figure 8-11).

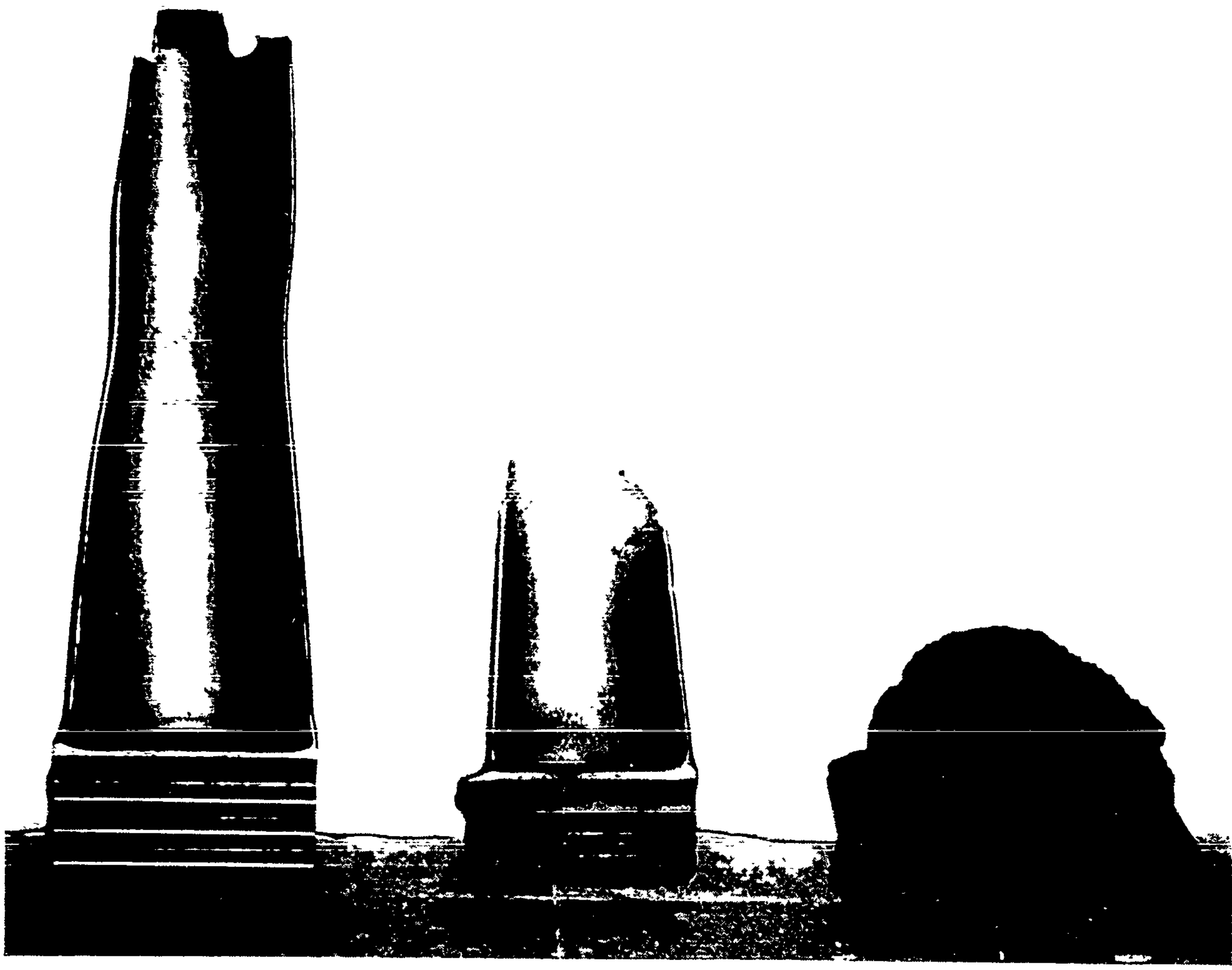


Figure 8-11. Turbine Blade Failures Due to: a) Overtemperature and Centrifugal Force, b) Temperature Stress Rupture, and c) Total Temperature Disintegration

2. Broach or disc failures are attributed to lack of quality control in fabricating and broaching the turbine disc, inadequate inspection procedures, and extended periods of overtemperature operation. Overtemperature operation is due to improperly set fuel controls, hot starts, inaccurate exhaust gas temperature sensing equipment, malfunctioning fuel nozzles, and too high allowable exhaust gas temperature. The never ceasing requirement to increase the performance of aircraft places the normal operating temperatures of the engine extremely close to the failure point. Failure of all the turbine buckets where the buckets are necked down and portions of the buckets have separated is caused by:

a. Thermal compressor stall where the airflow through the compressor is restricted.

b. Icing of air-inlet screens.

c. Closing or blocking of the air-inlet area to the compressor (birds, cloth, paper, or sheet metal).

d. Engaging the emergency fuel system with the throttle in full open position.

e. Too rapid throttle advancement when operating on the emergency system (same or similar to a and d, above)..

f. Too rapid throttle advancement when operating early type engines not incorporating automatic fuel metering systems.

8-44. Bearing Failures. Inadequate oil supply is the primary cause of most bearing failures. When bearing failure is suspected, maintenance records should be carefully examined for evidence of unusual oil consumption, for service history, and for recent periodic maintenance involving the lubrication system. The oil filter, lines, and seals should be examined for evidence of leaks, and the main lubrication pump and scavenge pumps inspected for failure or malfunction. Lubrication jets should be examined for evidence of misalignment and stoppage. A thorough knowledge of the lubricating system is required for analyzing particles removed from a pressure or scavenge pump that has failed.

8-45. Detection of bearing failure is not difficult on disassembly. The failed bearing will show evidence of severe galling, scraping, and distortion of both the inner and outer races, as well as overheating. A bearing failure caused by impact will reveal little or no galling or evidence of overheating except in localized areas where large forces were exerted. In most modern turbojet engines main bearing failure can be expected shortly after the oil supply is interrupted. Operating life is dependent, of course, on operating conditions when and immediately after oil starvation occurs. In the high-rpm ranges failure occurs very rapidly because most of the oil is used for bearing cooling. Once the flow is interrupted, bearing temperatures rise very quickly. The main thrust bearing is generally the first to fail because it is the most highly stressed and the most dependent on oil circulation for cooling. Occasionally other main bearings may fail before the thrust bearing, but evidence of damage to the thrust bearing will be present. On thrust bearing failure a vibration is felt as the compressor rotor shifts, with simultaneous blade interference in all stages, usually described as a muffled explosion or rumble. The rpm winds down rapidly to zero. There will generally be heavy metallization throughout the hot section as metal fragments pass through the engine.

8-46. Bearings may fail for reasons other than lack of lubrication. If the balls, rollers, retainers, or races fail, the indications may be similar to those described above. The failed bearing, however, will not exhibit the high overtemperature signs of those failing because of a lubrication problem. They may be broken and display blue flat spots but will not be burned and melted as in the case of oil starvation (see figures 8-12 and 8-13).

8-47. Engine Fire in Flight. Engine fire in flight is usually the result of a malfunction or failure of a component of a turbojet engine. Fires in flight, i.e., flame emitting from the tailpipe, can be attributed to compressor failures, compressor stall, fuel regulator malfunction, fuel nozzle malfunction, and fuel leakage of the basic engine or afterburner fuel system.

Figure 8-12. Bearing Falure Due to Oil Starvation

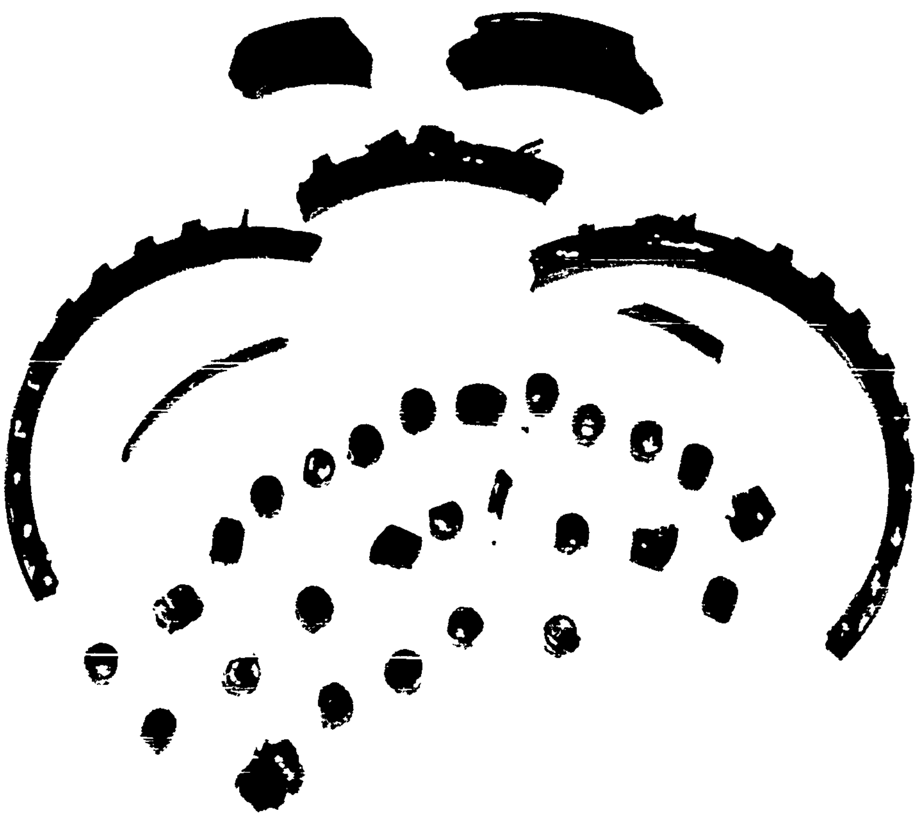


Figure 8-13. Bearing Failure Due to Impact Forces

8-48. Fuel System Failures and Malfunctions. The predominant cause for flameout in flight is the malfunction or failure of the fuel control system. An electronic fuel control system consists of a computing section and a metering section. The computing section monitors throttle position, burner pressure, engine rpm, and compressor inlet temperature. This is translated into a fuel demand that is relayed to the metering section, which meters the correct amount of fuel from fuel pump to the engine. The only method of positively determining that a failure or malfunction of the fuel control system existed is a test bench flow check at a rework facility or manufacturer's installation.

8-49. Another type of fuel control system consists of a main fuel regulator utilizing an rpm governor and a barometric altitude compensating unit. The compensating unit reduces fuel flow as the density altitude increases. The rpm governor maintains fuel flow contingent upon throttle setting in order to maintain the desired rpm. As with the electronic fuel control system, a test bench flow check is the only means of determining that a failure or malfunction existed. There is also a remote hydraulic control fuel system in limited use, and this system also requires a test bench flow check to ascertain its condition.

8-50. Main and emergency fuel pumps are seldom a source of trouble. The failures, if any, are usually manifested in shearing of the fuel pump drive shaft. Fuel nozzle malfunction is manifested in burned combustion chambers, transition liners, and nozzle diaphragm vanes aft of the fuel nozzles that have malfunctioned. Main fuel regulators, as a rule, do not cause overtemperature failure of the hot section of the engine. The emergency fuel control can be a prime cause factor in producing overtemperature of the hot section of the engine, especially during change-over to emergency operation with the throttle in the open position and the engine at a low rpm, or rapid throttle burst when operating on an emergency system.

8-51. Afterburner Malfunctions. The adaption of afterburners to various engines greatly increases the accident potential of the aircraft. Afterburner units flow approximately twice the fuel as that supplied to the basic engine. A minutely cross-threaded fuel system union, a crack in the afterburner fuel lines, or improperly torqued fittings can be cause for a major fire due to leakage of the system when subjected to the high fuel pressures and flows required for afterburner operation. The fatiguing and cracking of the afterburner fuel system is a greater potential hazard than failure of the basic engine fuel carrying system. This is due to the high frequency and amplitude of the vibration caused by afterburner operation. Fuel leaks of the afterburner system are immediate cause for ground or inflight fires as the fuel is instantly ignited upon contacting the hot combustion chamber of the afterburner. Inflight fires of this nature can usually be ascertained by the condition of the fuselage metal surrounding the afterburner. The metal in such cases would be hot-flowing in the direction of the airflow through the aircraft and around the aircraft in flight.

8-52. TURBOFAN ENGINES.

8-53. The turbofan engine is basically a variation of the twin-spool turbojet engine in which one or more turbine stages are used to drive a ducted fan, usually located at the front of the compressor section. Basically, the air passing through the fan bypasses the combustion process, exhausting from the engine with a lower amount of internal energy and a lower exhaust velocity than air leaving the turbine. The greater volume of air passing through the engine compensates for the lower energy of the exhaust air to produce the same amount of thrust as a comparable turbojet, but with lower exhaust velocity and fuel consumption. Investigative techniques for the turbofan are essentially the same as for a twinspool turbojet. However, the investigator must take into account the lower exhaust temperatures involved when applying the characteristics described for turbojets.

8-54. TURBOPROP ENGINES.

8-55. Turboprop engines employ a power turbine to drive a variable pitch propeller, which is the primary source of thrust. A small, secondary thrust is derived from the turbine exhaust. The propeller is coupled to the engine through a reduction gear and a torque sensing system. During flight, the engine maintains a constant speed, called the rated engine speed. Thrust is increased by increasing fuel flow, with the resultant rise in turbine inlet temperature producing an increase in engine torque. The torque sensing system converts the increased torque into additional thrust by increasing the propeller blade angle. Investigative techniques for the gas turbine portion of turboprop engines are identical to those for turbojets with the exception that engine speed is essentially constant. The investigator must also examine the additional mechanical systems incorporated by the turboprop: the propeller, reduction gear, and torque sensing system.

8-56. PROPELLERS. When properly correlated with evidence obtained from the engine, examination of the propeller can produce valuable evidence such as revealing whether power was being produced at the time of impact. The first step in propeller examination is to account for all blades. If any portions of the blades are missing, the breaks on the remaining portions should be examined with a magnifying glass to determine whether the breaks occurred in flight or at impact. Evidence of fatigue or tension breaks should be noted carefully. The next step should be an examination to determine whether power was being developed at time of impact. The most typical indications are as follows:

1. Blades bent forward near the tips indicate high power at time of impact.

2. Blades bent slightly rearward indicate rotation of the propeller at impact, but low or no power. This is usually associated with a windmilling condition.

3. Blades bent rearward to the extent that they have a pattern commonly referred to as "banana peeling". This condition indicates propeller was not rotating at time of impact (propeller was feathered).

8-57. The above indications will vary with the type of accident, and the degree of power developed. Moreover, the characteristics described will not always be found in cases where the aircraft is equipped with a hollow steel blade propeller as this type exhibits random bending and failure on impact. In these cases, the power being developed can be determined by noting the distance which portions of the blades are thrown from the scene of the main wreckage at impact, and by careful examination of the blade breaks.

8-58. In accidents in which the aircraft makes initial contact with the ground with the propellers, and is in a relatively flat pitch angle with a low rate of descent, the propeller or propellers will usually leave characteristic ground scars. These are commonly referred to as "prop bites." If these bites are evenly spaced and there are at least as many bites as there are prop blades, they may be used to compute the ground speed of the aircraft (see appendix F). In this computation, the assumption is made that the engine is operating at the rated engine speed, and the ratio of the engine speed to the propeller speed must enter into the computation.

8-59. To determine the propeller blade angle at time of impact, first examine the impact marks which will usually be found on the blade segment gears and the rotating cam gear. When these marks have been located, they should be matched and the blade angle reading taken at the blade angle index.

8-60. REDUCTION GEAR. The reduction gear couples the turbine shaft with the propeller while reducing the rpm from the rated engine speed to the normal propeller speed. The reduction gear assembly also contains the mechanical linkages necessary to prevent propeller overspeeding. Failure of this linkage can allow the propeller to overspeed with the possibility that the blades may be torn from the propeller hub by centrifugal force. Should the main reduction gear fail, there would be no torque transferred from the engine to the propeller and all propeller thrust would be lost. Investigators should examine the couplings between the reduction gear and the turbine shaft and propeller, as well as the internal mechanism of the reduction gear whenever failure of this assembly is suspected.

8-61. TORQUE SENSING SYSTEM. The torque sensing system senses changes in the torque transmitted by the engine to the propeller and compensates for it by varying the blade pitch-angle of the propeller. Failure of this system can cause erratic thrust and loss of control of the propeller.

52. TURBOSHAFT ENGINES.

8-63. Turboshaft engines are designed for use in helicopters. The gas turbine engine drives the main rotor(s) and tail rotor through a series of reduction gears. Virtually all of the power produced by the turbine not required by the compressor is transferred to the rotors, therefore the exhaust temperatures and exhaust gas velocities are practically negligible. With this exception, investigative techniques for the turboshaft engine are essentially the same as for turbojet engines. Additional characteristics of the associated mechanical equipment are described in the section on helicopters (see paragraph 8-91).

8-64. RECIPROCATING ENGINES.

65. Reciprocating engines are those powerplants that employ some type of piston-driven internal combustion engine to drive a propeller. Several of the most common symptoms of reciprocating engine malfunction and their causes are listed below for guidance. The fact that several of these symptoms are similar should forewarn the investigator of the possibility of assigning wrong-cause factors if a careful physical examination is not performed. Questioning witnesses as to the engine sounds they heard prior to impact may also produce vital information for the investigation.

1. Carburetor Icing. This is usually indicated by a gradual decrease in power, sputtering, intermittently rough operation, and erratic increases and decreases in power. In severe icing conditions the decrease in power may be rapid. nifold pressure and carburetor air temperature struments usually are the only engine instruments affected by carburetor icing.

2. Ignition Troubles. These are usually dicated by intermittently rough operation that develops into a steady miss, with vibration and loss of power. Some fuel is pumped through the engine unburned and causes afterfiring and rumbling in the exhaust system. Engine instruments will not be affected until the condition has progressed to a serious state.

3. Inadequate Fuel Flow. This is caused by obstructed or broken fuel lines or running out of gas. It is indicated by sputtering, erratic increases and decreases in power, and roughness. Manifold pressure, fuel flow, and fuel-pressure instruments will be affected.

4. Rich Fuel-Air Mixture. Intermittent missing and torching characterize this type of engine operation. Torching shows a long, dull red exhaust flame at night and heavy black smoke during the day. Cylinder head temperature will be below normal shortly after the mixture becomes rich, and after prolonged operation the oil temperature will read below normal. Manifold pressure and rpm instruments will show a loss of power.

5. Lean Fuel-Air Mixture. A lean mixture will cause detonation, preignition, and backfiring. It brings on a loss of power and finally engine failure. Engine temperature instruments will read above normal. Manifold pressure and rpm instruments will show a loss of power.

8-66. PRELIMINARY INVESTIGATION OF RECIPROCATING ENGINE FAILURE. The investigator should conduct a comprehensive examination of the engine to determine fairly obvious causes of failure or malfunction before deciding to ship it to a rework facility for a safety engineering investigation. However, care must be taken not to disturb or destroy evidence that may be used by the rework facility in their detailed and expert examination. The aircraft accident board should insure that the capabilities of the squadron or unit are not exceeded when and if it is decided to examine some internal components or accessories. The preliminary investigation should include:

1. All sump plugs, magnetic and other, for foreign material which might indicate plugging of oil lines or internal engine component

failure; and preservation of the oil for further examination if necessary.

2. All spark plugs for general condition, cleanliness, proper gap, condensation, and evidence of detonation.

3. Carburetor for presence of gasoline leaks in housing, fuel filters, position of throttle, and mixture controls.

4. Ignition system for harness and wiring condition and position of switches.

5. Oil system for dirt or chemical content of filters, loose connections or fatigue failures of lines, oil content, and cleanliness of tanks.

6. Fuel system for items similar to those listed under 5 for oil system, plus position of fuel selector valves.

7. Hydraulic system for cleanliness of fluid and broken hoses, filters, and loose connections.

8. Engine controls so that their position and condition can be noted.

9. Combustion chambers to determine if any of them had not been firing and was coated with oil or heavy deposits.

8-67. The investigator can gain valuable information concerning events just prior to impact by a careful study of the propellers. Except in cases of the most extreme impact damage and disintegration, the propeller governor head will usually be found sufficiently intact to yield valid results when a bench check is conducted. This check will reveal the rpm for which the pilot had the propellers set (see paragraph 8-56 for a description of investigative techniques for propellers).

8-68. If the aircraft struck the ground with a shallow impact angle, there may be propeller ground scars which can provide additional information. If the distance between "prop bites" is measured, then either ground speed or engine rpm can be calculated (see appendix F) if one of the two quantities is known.

8-69. SYSTEMS FAILURES.

8-70. The complexity of the systems in modern aircraft and their relationship to each other have resulted in failures, malfunctions, and improper operation by the pilot. All of these have been identified as cause factors in major accidents. Their complexity further subjects them to failures when they are improperly maintained. For these reasons, the investigator should be sure that he has included a careful examination of all systems on the aircraft as a part of his investigation. Each accident will present its own problems and the extent of the examination will be determined on the basis of the circumstances involved in each case. The inspections outlined in the following sections, however, are considered the minimum and should be conducted in all cases.

8-71. FUEL SYSTEM.

8-72. DETERMINATION OF FUEL ON BOARD. The first thing which should be determined regarding the fuel system is the amount of fuel on board at time of impact. This may be done in several ways:

1. Measuring the amount in the tank, in those accidents in which the tanks are intact.

2. Noting fuel in the area adjacent to the wreckage and the type of tank failure, and estimating the amount on board. When all breaks in the fuel tanks are inward or crushed, the indication is that they were empty. If the breaks are outward, the indications are that they were relatively full.

3. Noting the indications of the fuel gages in the cockpit. There are two types of electric gages in use on aircraft, and their indications are entirely different. The autosyn, or resistance type, returns to either zero or "full" when the electric circuit is broken by severing of the wires at impact. For this reason, no constructive evidence can be gained from their indication. The

selsyn, or rotating gear type, remains in whatever position it was in prior to the severing of the wires, and its indications are usually reliable.

4. Investigation of the records and interviews with servicing personnel should reveal the amount of fuel on board at time of takeoff. By utilizing this information, together with the known facts regarding duration of flight, cruising altitude, cruising thrust, and cruising rpm, the investigator can calculate how much fuel should have been on board at the time of the accident. Discrepancies may indicate either engine malfunction or improper fuel management.

8-73. FUEL VALVES AND CONTROLS. The position of the fuel selector valves will usually indicate which engines were being fed from which fuel tanks. Evidence revealed by examination of these valves is usually reliable as they operate in a rotary direction and, unlike components which operate in a fore-and-aft direction, are not affected by impact. The position of fuel valves may also reveal whether a single-engine aircraft has had a forced landing accident that was caused by fuel starvation as a result of running out of fuel or fuel starvation as a result of fuel mismanagement on the part of the pilot. Fuel pumps and the fuel control system should be bench checked to determine whether they were operating properly at the time of impact. Failure or malfunction of these components could also lead to fuel starvation or engine malfunction.

8-74. FUEL CONTAMINATION. In any accident where fuel contamination by foreign material or use of wrong fuel is suspected, a sample of the fuel should be taken for detailed laboratory analysis. As a guide in determining whether a wrong type of fuel has been used, see Appendix I for identification colors of aircraft fuels. This is the only method of determining fuel types by visual inspection in the field. Detailed analysis to determine exact specifications must be made by a properly equipped laboratory at a rework facility. Examination of the remaining components of the fuel system should normally include:

1. All fuel lines from the tanks to the combustion chamber for loose connections, corrosion, foreign material and fatigue breaks.

2. Fuel pumps to determine operation at time of impact. Rotation at time of impact will be indicated by rotational scoring of the pump vanes or gears (depending on the type of pump) and the pump housing. The most common cause of pump failure is a broken pump drive shaft. Failure of the shaft can be identified by a torsion break, usually accompanied by evidence of metal fatigue.

3. Fuel filters for foreign material or evidence of chemical reaction. If either of these is found, reseal the filter and retain it for laboratory analysis.

4. Preflight fuel samples for contamination. Laboratory analysis will be required to detect contamination of fuel in the sample taken before the flight, since any visible contaminants would have been discovered when the sample was taken.

8-75. HYDRAULIC SYSTEM.

8-76. The items mentioned under fuel systems regarding lines, filters, and pumps also apply to the hydraulic system. In addition, it should be remembered that on most aircraft, the flight control system is hydraulically actuated. In these aircraft, the utmost care must be given to the hydraulic system. The maneuvers being performed prior to the accident may point to hydraulic flight control system malfunction. Most aircraft have at least two independent hydraulic systems, each capable of operating the primary flight controls, so a failure of one system would probably not cripple the aircraft. Therefore, the investigator should study the system carefully. He should determine exactly what kind of a malfunction could produce the flight condition encountered, and then inspect the system to determine whether that malfunction occurred.

8-77. A large percentage of malfunctions of hydraulic flight control systems are believed to be caused by foreign material (see figure 8-14). For this reason, actuating cylinders and filters should

Figure 8-14. Slider-Valve Failure Caused by Improper Plating

be most carefully examined. Also, the methods employed by maintenance personnel in cleaning filters and protecting open hydraulic lines from contamination during repairs should be carefully evaluated.

8-78. Examination of specific components of the hydraulic system should be performed in accordance with the following guidelines:

1. Hydraulic Pumps. The drive coupling of the pump should be checked for failure. A battered and somewhat polished appearance of fracture surfaces of a sheared coupling indicates that the coupling failed while the pump was in operation and the driving source continued to operate. If the fracture surfaces are clean and otherwise undamaged, the pump and driving source were not rotating at the time of failure, and failure most likely occurred at impact.

2. Accumulators. Check the position of the piston relative to the air and fluid ends of the cylinder.

WARNING

Hydraulic system accumulators should be handled with extreme care due to their high internal pressures.

The position of the piston can be related to the sequence of loss of hydraulic and air pressures in the system.

3. Pressure Regulators and Relief Valve These components should be checked for positio and settings at the time of impact and, if discrepancies are found, bench checked to determine if they were operating properly.

4. Selector Valves and Actuators. Positions of these components will indicate the aircraft configuration and flight attitude at impact.

5. Filters and Plumbing. Check for evidence of leakage, corrosion, chemical reaction, or contamination. "B" nuts should be checked for proper torque. Torque on the nuts can be stress relieved by impact or fire damage; therefore, a nut must be backed off more than one-half turn to provide a reliable indication that it was improperly torqued.

6. A hydraulic fluid sample should be taken as soon as possible on arrival at the accident scene. This sample should consist of at least 100 milliliters of fluid, one sample from each system. These samples should be sent to a properly equipped laboratory and examined for foreign matter, water, and chemical reaction.

8-79. ELECTRICAL SYSTEM.

8-80. Recent studies of aircraft accident reports indicate that an increasing percentage of accidents are attributable to electrical system failures. However, the usually inadequate coverage of the electrical aspects involved in such accidents is indicative of the inability to keep abreast of design trends. The design, operation, and maintenance of the electric power system in naval aircraft has many facets. In some aircraft, it is merely of auxiliary importance, in others the safe control of the aircraft is directly dependent upon electric power.

8-81. A considerable portion of the accidents which occur that involve malfunction or defective material are not due entirely to defective material or to personnel errors at the working level, but can more properly be ascribed to difficulties associated with the distribution and dissemination of technical and operating information within individual commands. Examination of the electrical system should include but not be limited to:

1. All electrical switches, for evidence of malfunction and for recording of position at time of impact. It should be borne in mind that switches operating in a fore and aft direction are highly subject to movement by impact, and their position should be carefully correlated with other evidence before a definite conclusion is reached regarding the position prior to impact.

2. Circuit breakers, to determine their position prior to impact and the relation that position may have with other evidence. Note that the position in which the circuit breakers are found is an unreliable indication of their position prior to impact. The investigator must look for other means of verifying their position, i.e., evidence of arcing or burning at the circuit breaker panel or elsewhere in the circuit.

3. Installation of terminals for improper splices or terminals being used, creating a high resistance and resulting in overloaded circuits.

4. Electrical insulation for evidence of breaking down due to chafing.

5. All recoverable wiring, to determine whether short circuits, current overloads, or other potential overheat causes existed prior to impact. When wiring is found to have fire or other internal overheat evidence present, it should be submitted to the appropriate agency for laboratory analysis. This analysis can often reveal whether the heat originated from an external source or from the wiring itself as a result of a short or overload. The wiring should also be examined to determine any potential overheat sources caused by improper routing or clamping.

6. Diligent search for any evidence of electrical malfunctions which may have caused other systems to malfunction. It should be remembered that fuel, hydraulic, and other system components are electrically operated on many aircraft.

7. All electrically operated units, such as starters, generators, and motors, to determine whether they were rotating at the time of impact.

8. All terminals and breakers in wires that were torn apart at impact, to determine if current was passing through the system at the time of impact. This can usually be determined by evidence of arcing.

9. Functional check of trim tab switches. Malfunction of these switches can cause runaway trim tabs with resultant uncontrollability of the aircraft.

10. Inspection of the instructions set forth in the NATOPS Manual for adequacy as a guide for appropriate steps to be taken if electrical failure is a factor.

11. Inspection of the electric power diagram in the NATOPS Manual to insure that a clear and concise guide for emergency operation of the electric power system exists.

12. Inspection of other squadron and/or air station aircraft of like type for peculiarities of electric power controls that tend to make proper system control more difficult.

13. Inspection of routine preventive measures employed for ascertaining correct operation of the electric power system.

14. Inspection of light bulbs for evidence that they were on at impact. If the filament of a light bulb is heated and the bulb is then subjected to shock, such as occurs at impact, the filament will be stretched and distorted (see figure 8-15). This can provide valuable information as to whether any emergency or warning lights were lit prior to impact.

15. Inspection of electrically driven back-up flight control system, on those aircraft so equipped, to determine whether the motor was in operation prior to impact. Activation of back-up systems is indicative of main and/or secondary hydraulic system failure.

8-82 RADIOACTIVE TUBES. Certain jet engines use spark-gap tubes that contain radioactive material. These tubes contain radioisotopes of uranium. If the spark-gap tubes are broken, they present an internal health hazard. Uranium, to be considered a health hazard, must physically enter the body. This may be accomplished by inhalation, ingestion, or allowing contaminated materials to touch an open wound such as a cut or scratch. Uranium is primarily an alpha particle emitter and therefore does not constitute an external radiation hazard because alpha particles travel only a few centimeters in air and generally do not penetrate the outer layer of skin.

8-83 Under normal circumstances, only skilled personnel will work on the ignition unit, and these individuals should be thoroughly familiar with the proper method of handling radioactive

Figure 8-15. [illegible]

materials. Anyone who handles engines or aircraft parts, however, should also be aware of the presence of a tube containing radioactive material and exercise caution whenever any doubt exists. Unnecessary handling of any potentially hazardous material is unwise.

8-84. It should be understood that there is no danger of radiation in normal handling of these engines or ignition units. If the spark-gap tube is broken, however, all safety precautions for handling, storage, and disposal of such radioactive material should be observed. If it is not certain whether a particular engine has this spark-gap unit, it is suggested that the engine manufacturer be contacted so that whatever safety procedures are required to handle these units safely may be set up.

8-85. AUTOMATIC FLIGHT CONTROL SYSTEMS.

8-86. The complexity of the automatic flight control systems in modern aircraft, and the small quantities of fluid involved in their operation, makes them highly susceptible to malfunction or failure (see figure 8-16), and this system has been determined to be a cause or contributory factor

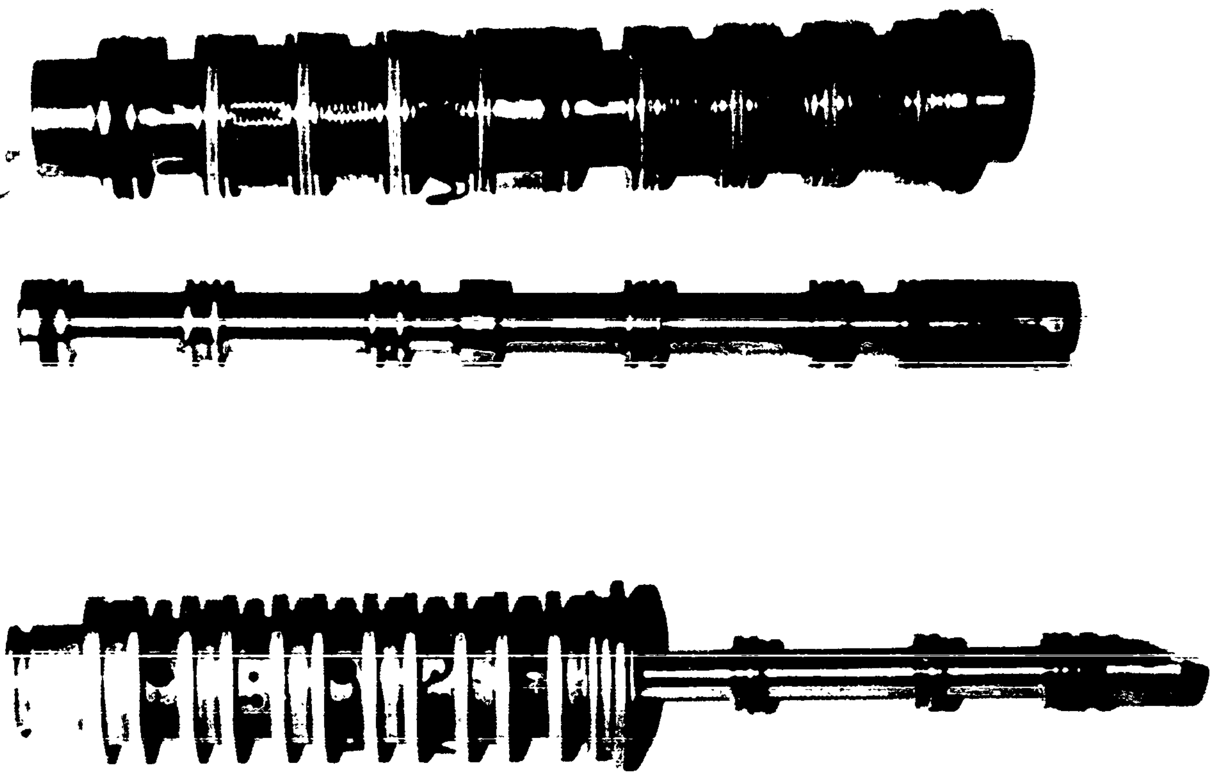


Figure 8-16. Flight Control Slider Valves—Very Susceptible to Contamination

in a number of accidents. In the stability augmentation mode, an automatic flight control system (AFCS) acts to damp out oscillations of the aircraft about the pitch, roll, and yaw axes by slight movements of the control surfaces. In the auto mode, the AFCS will maintain aircraft heading, attitude, altitude, and Mach number. The AFCS can be overridden by the pilot by movement of the control stick. Depending on the system a pilot override will either disengage or interrupt the AFCS. Malfunction of the AFCS can be caused by malfunction or failure of the hydraulic, electrical, or fuel systems, and can result in the pilot's inability to override the system in an emergency. Examination of the AFCS requires technical assistance from a NARF or the manufacturer, and the investigator should limit himself to noting the positions of all switches related to the AFCS to determine if the AFCS was in operation at the time of impact and all switches were in their proper positions.

8-87. Some aircraft also incorporate an approach power compensator system which is used to maintain a constant average angle of attack during approaches to landing. Malfunctions of this system are especially serious since the system is used during a critical phase of flight.

8-88. Some helicopters employ automatic stabilization equipment which provides attitude and altitude stabilization as well as automatic approach and hover capabilities. Since helicopters are inherently unstable, failure of this equipment can result in loss of control of the aircraft.

8-89. EMERGENCY SYSTEMS.

8-90. Although emergency systems are not often found to be subject to malfunctions that can be assessed as either primary or contributing cause factors to an accident, locating and making corrective recommendations to eliminate malfunctions can often make an important contribution toward the saving of lives. For this reason, every possible effort should be made to determine whether or not use was made of any of the following systems, and whether they were functioning satisfactorily.

1. Oxygen System. Check the oxygen converters for quantity of liquid oxygen and insure they are free of contamination. Check oxygen lines, valves, regulators, and masks for evidence of leaks, corrosion, and contamination.

2. Canopy. Check hinges and latches for evidence of failure; inspect canopy jettison system to determine if an attempt was made to jettison the canopy.

3. Ejection Seat (see figure 8-17).

WARNING

Ejection seats contain explosive charges which can cause fatal injury and serious damage to equipment. Investigators should insure that ejection seats are disarmed or safety pins inserted by qualified personnel before beginning their examination.

Seats should be carefully inspected to determine whether an attempted ejection occurred before impact. If this is the case, the seat and its explosive charges should be examined by a cognizant rework facility to determine the cause of the malfunction. Check the following components of the seat for failure or malfunction:

a. Emergency harness release handle. In many aircraft, actuation or malfunction of this mechanism may interfere with proper ejection seat sequencing.

b. Primary and secondary firing mechanisms, drogue gun, and main charges for proper installation.

c. Time release mechanism, barostat, "G" controller, inertial reel mechanism, and leg restraints for proper operation.

d. Oxygen bottle for proper charge.

4. Parachute.

5. Shoulder Harness and Seat Belt.

6. "G"-Suit, "G"-Valve, and Pressure Lines.

7. Pressure Suit.

8. Life Raft.

8-91. **HELICOPTERS.**

8-92. Investigation of helicopter accidents presents some unique problems to the investigator. With the slower flight speeds and different modes of flight involved, helicopter wreckage will seldom conform to patterns described for fixed-wing aircraft (see figure 8-18). There are three main types of crashes involving helicopters.

1. Autorotation. When a helicopter loses power from its engine, the rotor can be dis-

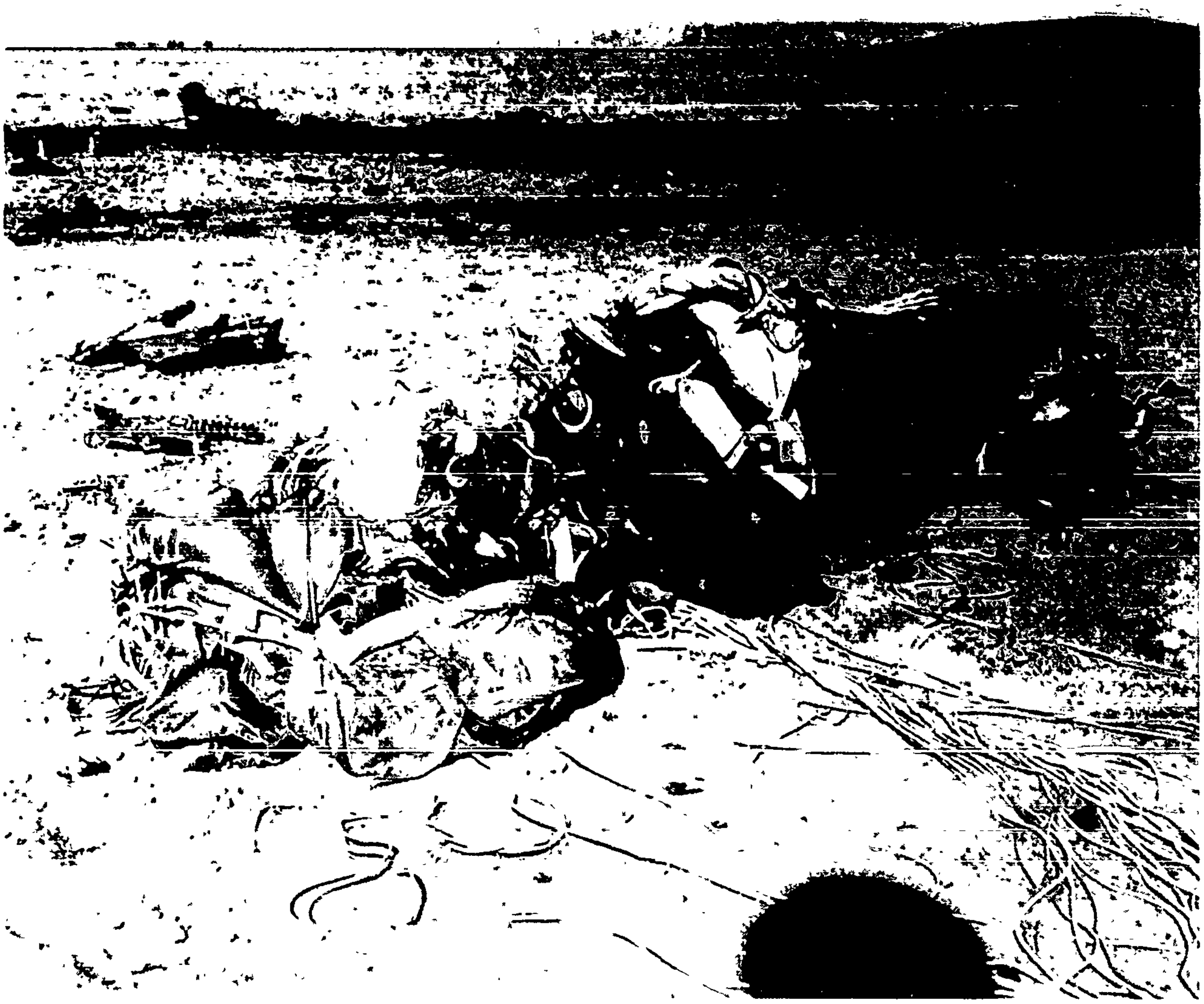


Figure 8-17. Ejection Seat Failure

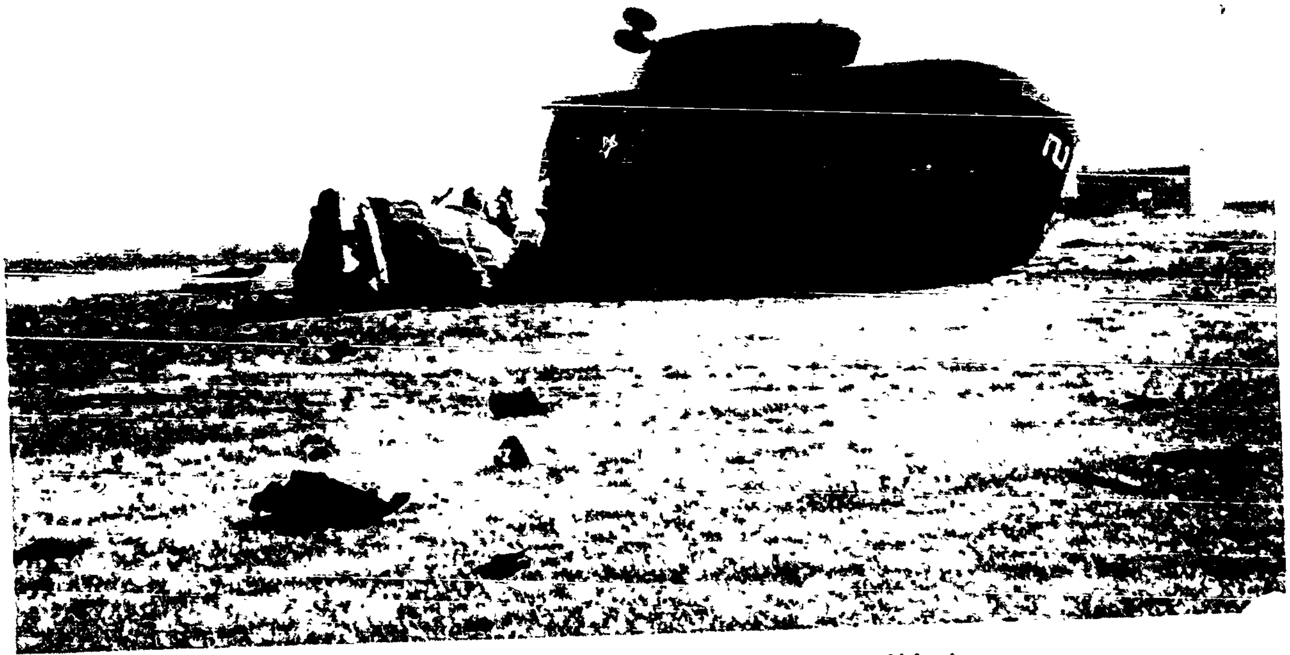


Figure 8-18. Helicopter Loss of Power at Low Altitude

engaged from the reduction gear, allowing the helicopter to descend in controlled flight. If the power loss occurred at a high enough altitude, the windmilling rotor will produce sufficient lift to slow the helicopters' rate of descent to slightly higher than normal. This type of emergency landing is known as autorotation and will generally result in relatively minor damage to the airframe provided the pilot adheres to proper procedure.

2. Dives into the Ground. This type of crash generally results in extensive damage to the airframe. The major causes of these accidents are inflight structural failure of the main rotor mechanism or airframe, resulting in loss of flight control, or from loss of power with insufficient airspeed or altitude to affect an autorotative landing (see figure 8-19).

3. Rapid Rotation About Vertical Axis. This type of accident is peculiar to single-rotor helicopters and is the result of a failure or malfunction of the tail rotor. Damage to the helicopter is dependent on the airspeed and velocity at the time of failure, and can vary anywhere between the extremes of the autorotation and dive-into-the-ground accidents.

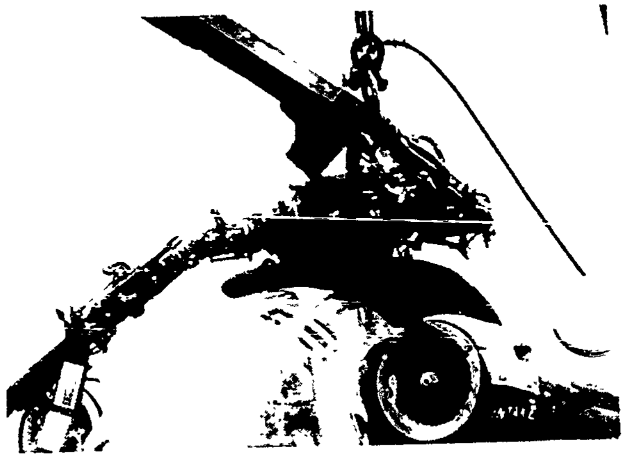
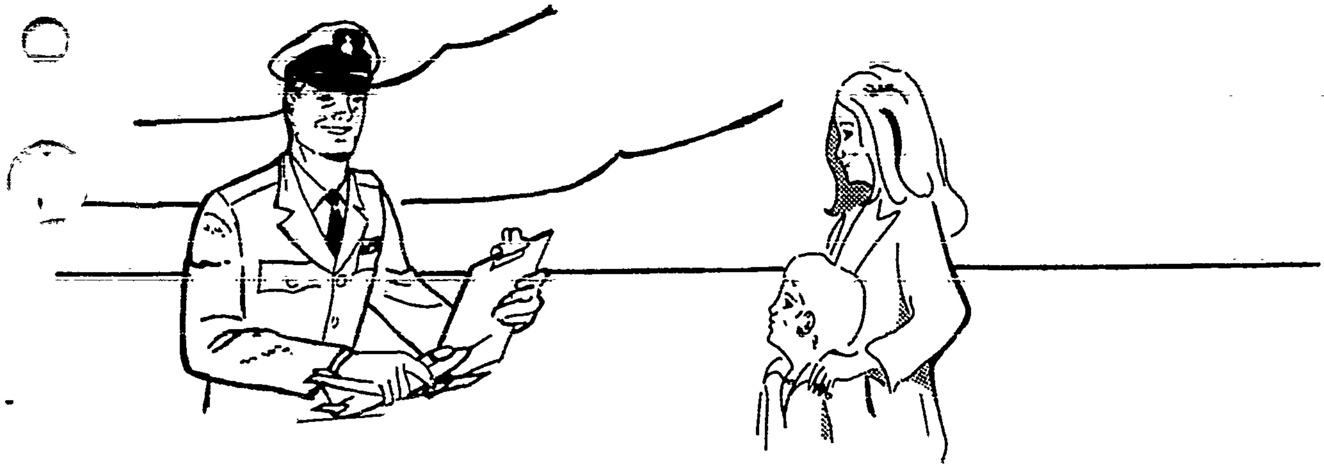


Figure 8-19. Helicopter Rotor Mechanism Failure

8-93. Present naval helicopters employ turbo-shaft powerplants. Investigative techniques are as described in paragraph 8-62. There are additional factors involved, however, due to the complicated linkage system involving the engine, main rotor and tail rotor. Since the main rotor provides both lift and thrust, the rotor control mechanism must allow the blades three axes of freedom, i.e., the blades must be able to move up and down, forward and aft, and change angle of attack. The tail rotor provides thrust to counteract the torque produced by the main rotor, and directional control is maintained by varying this thrust. The investigator must examine the linkages between the flight controls and the main and tail rotor control assemblies for mechanical failure or malfunction.

8-94. Investigative techniques involving fuel, hydraulic, electrical, and emergency systems are identical with those for fixed-wing aircraft to whatever extent the helicopter is equipped with these systems.



CHAPTER 9

WITNESSES

9-1. DEFINITION.

9-2. For the purpose of investigating an aircraft accident, the term witness is a general term referring to those persons who may be connected, even remotely, with the accident. The witness may be the surviving pilot or member of the crew, or those personnel who were responsible for maintaining, servicing, scheduling, and controlling the aircraft on the ground or in flight. It also includes persons who are not directly connected with the operation of the aircraft, but who actually saw or heard some portion of, or a series of, events leading up to and including the actual accident as well as recognized experts in a given field when brought in to provide technical data, theory of system operations or to give opinion on speculative postulations which the board may wish to explore. Manufacturer's field representatives would be exemplary of the latter.

. INTERVIEWING WITNESSES.

9-4. To obtain maximum cooperation from a witness, it is important to explain the privileged status of his statement. The aircraft accident report that is submitted in accordance with the current OPNAV instructions governing aircraft accident reporting can be used only for accident prevention purposes. The purpose of this privilege is to insure full disclosure by the witness of all facts pertaining to the accident of which he has knowledge. It is generally necessary to explain that the accident board is attempting to determine the cause of the accident to prevent a similar occurrence in the future and that the statement given the board will be used in no other way. Frequently an aircraft accident requires an investigation pursuant to the provisions of the Manual of the Judge Advocate General (JAGINST 5800.7A). This investigation may be conducted at the same time as the aircraft accident investigation. If other Federal agencies are involved, representatives of these investigative bodies may also be conducting their own investigation. As a consequence, witnesses may be interviewed by personnel from several investigative bodies. The fact that these interviews are held separately is confusing to the average witness and a lack of understanding of the difference in constitution and purpose of these separate boards may lead to a reluctance to cooperate fully with the aircraft accident investigators. Every effort should be made, therefore, to acquaint the witness with the specific and limited purpose of the aircraft accident board, and of the strictly limited use that will be made of his statement to the aircraft accident investigator.

9-5. TYPES OF WITNESSES.

9-6. Witnesses are divided into various categories as follows:

1. Expert Witnesses. Technically qualified persons who may be called upon to give their opinions upon any technical questions arising out of the accident.

2. Eyewitnesses. Persons who actually saw the accident or saw anything relevant to the subject matter of the investigation.

3. Other Witnesses. Persons who speak of any fact which is within their own knowledge and has relevance to the accident or the investigation.

9-7. IMPORTANCE OF WITNESSES.

9-8. The importance of witness testimony cannot be overstressed. Witnesses' statements and physical evidence go hand in hand in determining the cause of an accident. Each may complement or clarify the other.

9-9. The evidence obtained from witnesses should be as complete and detailed as possible. It should not be confined solely to the moment of the accident and the subsequent events but should cover all matters preceding the accident that may have any bearing on it. Pertinent matters prior to the accident include the maintenance of the aircraft, personal stresses that may have effected the performance of the flight crew, etc.

9-10. Investigators should bear in mind that statements that may be available immediately following an accident may be difficult or impossible to secure from witnesses or participants at some later time. It is therefore important that all witnesses be interviewed and their complete statements taken as soon as possible after the accident. The information elicited may help keep a pilot alive in the future or save very valuable equipment.

9-11. LOCATING WITNESSES.

9-12. Witnesses must be located and interviewed as soon as possible. Evaluation of their statements may tell the investigator the particular area in which the investigation should be concentrated, and by this means conserve the time and energies of the entire investigating team.

9-13. It is usually reasonable to assume that spectators and sightseers who are at the scene when the investigator arrives heard or saw something that attracted their attention to the aircraft and brought them to the scene. Talking to these people immediately on arrival may give the investigator information regarding the flight of the aircraft prior to impact. Also, from the sounds these people heard, he may be able to determine whether engine failure or other malfunction occurred prior to impact.

9-14. Efforts to locate witnesses should not be confined to the actual scene of the accident. It may happen that a person many miles from the wreckage has some relevant information to give. This is especially applicable in cases of suspected engine or structural failure, weather accidents, and fire in flight. Evidence of smoke, fire, low flying, unusual maneuvers, erratic engine operation, structural failure, and loss of control may be obtained from observers along the route flown who were not necessarily witnesses to the actual crash. A normal amount of effort may reveal witnesses to important events along the course of the flight where the trouble initially started. The crews of other aircraft in the vicinity at the time of the accident may be particularly helpful in establishing actual weather conditions. The pilots of other aircraft and airways communications stations may also be helpful in relating transmitted messages of vital importance.

9-15. Bear in mind that statements taken from witnesses located immediately after the accident, before they have time to compare stories with other witnesses, are often the most reliable. Get a statement, even though a brief one, from all witnesses as soon as they can be located. The witnesses can always be visited again, or called before the board at a later time if additional information or clarification of their statements is needed. However, the human mind has the tendency to fill gaps in recollection with logic and the longer a witness has to reconsider the events, the more unconsciously logic-tainted his testimony will be.

9-16. Local police and news reporters can often be helpful in locating witnesses. These people, particularly reporters, are interested in interviewing witnesses, and it is quite possible that they will have found some witnesses having valuable information before the investigator arrives.

9-17. INTERVIEWING TECHNIQUES.

9-18. Interviewing witnesses is one of the most important aspects of an investigation, and it is often one of the most difficult. This task may be facilitated by an understanding of some of the basic techniques of interviewing. Key factors in these techniques are: validity, reliability, purpose, planning, consideration of language used, use of pauses, and the knack of getting the subject to do the talking.

1. An interview is valid to the degree that the information gathered is a true account of the actual circumstances as they occurred. Validity will suffer seriously when the investigator is inept in his interviewing techniques and elicits information that is not related to the real circumstances. The best advice in this regard is stick to the point.

2. The reliability of the interview is another point that must be considered. An interview is reliable to the degree that the same information obtained in the first interview will be obtained in subsequent interviews.

3. The unplanned interview tends to be a spontaneous give-and-take between two people. The low reliability of the unplanned interview may be raised substantially by systematic planning beforehand. Planning should be in terms of general areas rather than in terms of a prepared list of questions. The areas into which the interviewer should plan to direct his inquiry will be determined by the purpose of the interview. Area planning has the following advantages: it eliminates the tendency of the person being interviewed to answer yes or no to a prepared list of specific questions; it facilitates sticking to the business at hand and prevents getting into discussions of irrelevant subjects; and the interview is less stilted and rigid. The fewer the questions, the less the interview seems like an inquisition.

4. The interviewer should do as little of the talking as possible and have the interviewee do most of the talking. Interviewing is an art, not a science; therefore, it takes experience to keep the interviewee talking. One of the most effective devices for keeping a person talking without a direct question from the interviewer is the puase. The pause is best employed following an assertion by the interviewee. Research has shown that pauses as long as 10 to 40 seconds may be used effectively.

5. Taking copious notes during an interview interferes with the flow of information and adds to the length of the interview. The best procedure is to use a tape recorder during the interview and transcribe the witness' statement when it is convenient. If there is no tape recorder available, or if the witness seems hesitant about talking into a microphone, an alternate procedure is to take as few notes as possible during the interview, filling in the planned areas immediately after the interview.

9-19. ADDITIONAL INTERVIEWING PROCEDURES. In interviewing witnesses, the follow-

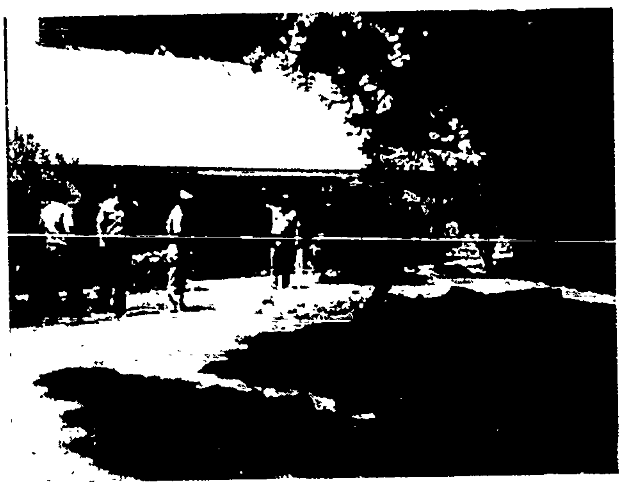


Figure 9-1. Eyewitnesses Provide Valuable Accounts of Accident

ing suggested procedures may be helpful.

1. It should be emphasized to the witness that he should speak only of matters within his personal knowledge; that is, what he, himself, saw or heard, and not hearsay evidence.

2. The witness should begin by giving his or her name, address, occupation, and aviation experience, if any, and, in the case of children, his or her age.

3. Witnesses should be encouraged to tell in their own words all they know about the accident. Do not attempt to put words in their mouths.

4. While they are giving their stories, they should not be interrupted except to prevent them from going off into irrelevant matters.

5. After a witness has finished, questions should be put to him to clarify doubtful points which may arise on his statement, but questions should not be phrased in such a manner as to suggest the answers.

6. The use of highly technical terms when asking questions of a witness who may have no knowledge of aeronautics should be avoided.

7. A witness should be treated with utmost courtesy at all times and any semblance of coercion avoided.

8. A witness may be able to express his statement better by sketches than words. Such sketches are acceptable as clarification of his evidence.

9. Whenever a witness refers to maps or photographs, they should be identified in his evidence or statement by reference to exhibit numbers, and the points mentioned should be identified, both on the map or photograph, and in the statement or record of evidence.

10. A transcript should be made of the tape recorded during the interview or of the notes taken by the interviewer, and this transcript will comprise the witness' statement. Since this statement cannot be used in any legal action, the witness' signature is not required.

9-20. INFORMATION FROM EYEWITNESSES

9-21. Witnesses who observed or heard the aircraft just before its crash should be asked for the following information when interviewed:

1. Time of mishap.

2. Local weather, particularly direction and strength of wind, visibility, rain, sleet, snow, or ice, thunder, and temperature.

3. Everything seen and heard of the aircraft in question and other aircraft in the neighborhood at the time, i.e., altitude, direction and attitude, unusual maneuvers or circumstances, etc.

4. Position of bodies, relative to the crash and evidence regarding use or attempted use of ejection seats and/or parachutes.

5. Dropping of flares or firing of lights.

6. Fire in the air or after impact; the time factor should be considered.

7. Whether anything, believed to have come from the aircraft, has been found lying apart from the main wreckage.

8. Description of articles seen falling from aircraft.

9-22. CORROBORATION.

9-23. It is particularly important that evidence of eyewitnesses should be corroborated, since a witness may be honestly mistaken as to what he actually saw. It is valuable to obtain the evidence of witnesses who were located at different vantage points in order that a clear picture may be given. The evidence can then be compared and any widely divergent stories can usually be detected and investigated further. The evidence of children is often valuable, but particular care should be taken in their cases to secure corroboration. However, all witnesses' statements should be taken and the validity of their statements established during the course of the investigation.

9-24. EVALUATION.

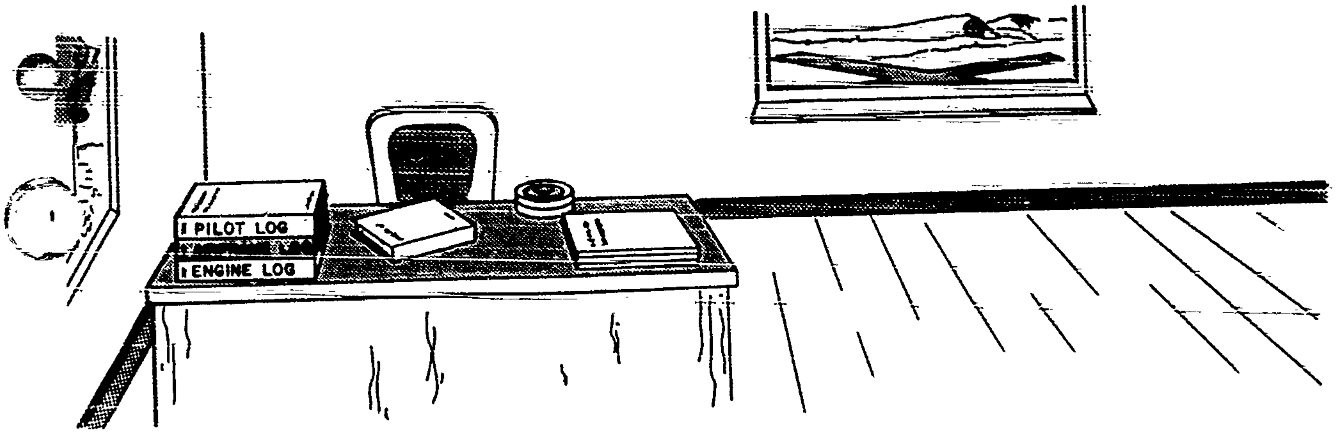
9-25. When a number of witnesses interviewed have given divergent stories of the accident, the witnesses' statement must be compared to find where the preponderance of evidence lies. This evaluation is best performed by listing the main points regarding the accident, such as heading, speed, altitude, unstable motions, signs of fire, falling objects, etc. If the testimony of the various witnesses is then listed beside the main points, a clear picture is quickly obtained of the majority view of what occurred just before the crash.

9-26. QUALIFYING WITNESSES.

9-27. It is just as important to qualify witnesses properly as it is to obtain their testimony. In general, younger men and boys are better witnesses because their knowledge of, and interest in, aviation enables them to understand and describe airplane maneuvers more accurately than their elders. Proper evaluation of testimony can be made only if the witness' aeronautical experience, or lack of it, is accurately evaluated by the investigator.

9-28. Many times it is helpful if the witness is asked to mark his points of observation on a map or sketch and refer to the exhibit number in his testimony. Use of airplane models can aid witnesses in describing the aircraft's attitude just before impact.

9-29. Following an interview, it is entirely appropriate for the investigator to note on the statement of the witness his own opinion of the credibility of the witness and his reasons for believing or discounting the information presented.



CHAPTER 10

RECORDS

10-1. INTRODUCTION.

10-2. One of the most important aspects of conducting any type of investigation is the accumulation of data and information. This is especially true when a board of naval officers is preparing an aircraft accident report that contains valid conclusions and considered recommendations that will enhance a vigorous, Navy-wide safety program. When the board arrives at the final phase of the investigation, which is the analysis of all information that has been gathered by the assigned task groups, every possible bit of information that may be pertinent must be considered.

10-3. One of the most fertile sources of information that should be fully and conscientiously explored is records. Even when the investigator is faced with a situation in which the wreckage is lost at sea and there are no survivors or witnesses, a thorough review of all records will enable him arrive at valid conclusions concerning the most probable cause of the accident. When record analysis does not reveal a causal factor, it will highlight general areas in maintenance or operations that may be beneficial to the safety of other operations. Even though certain records may be common to several phases of the investigation they can, in general, be divided into groups to conform to the suggested organizational groups.

10-4. OPERATIONAL RECORDS.

10-5. The operations task group should search for and review all records that dealt with inflight progress, procedures, conditions, and operating factors. Some of them are listed below:

1. Flight plan
2. Weather
3. Mission briefing
4. Navigation aids
5. FAA ARTC records
6. Weight and balance records
7. Tower transcripts
8. GCI station records
9. Clearance records

10. Refueling and servicing records

11. Flight schedule

10-6. PERSONNEL RECORDS.

10-7. It is necessary to gather all possible information that will enable the investigator to know as much about the flight crew, their training, techniques, background, capabilities, and limitations as possible. Some of the more important information that must be obtained from the records is listed below.

10-8. PILOT AND COPILOT.

1. Name, MOS, date commissioned NA or NFO
2. Age
3. Date entered service
4. Date released and recalled to active duty if reserve pilot
5. Date of NATOPS qualification in aircraft
6. Formal training in aircraft prior to checkout
7. Squadron lectures attended
8. Primary duty assignment
9. Collateral duty assignment
10. Total pilot hours
11. Pilot hours last 30, 60, 90 days
12. Pilot hours in type last 30, 60, 90 days
13. Instrument hours last 30, 60, 90 days
14. Night hours last 30, 60, 90 days
15. Flight hours last 24 hours
16. Total jet hours
17. Type of instrument card held
18. Expiration of instrument card
19. Total time in type

10-9. OTHER CREW MEMBERS.

1. Crew position
2. Formal training for crew position
3. Experience as crewman
4. Recent experience as crewman

10-10. MATERIAL AND MAINTENANCE RECORDS.

10-11. In the field of aircraft accident investigation a great amount of information is available to the investigator in squadron maintenance records. In all accidents, it is imperative that these records be reviewed. This is especially true when material failure or systems malfunction is suspected.

10-12. POWERPLANT.

1. Last periodic inspection
2. Date of last periodic inspection
3. Time since last inspection
4. Engine(s) model and serial number(s)
5. Total hours
6. Number of overhauls
7. Hours since last overhaul
8. Overhaul activity
9. Record of engine bulletins incorporated

10. Engine bulletins and service changes not incorporated

11. Serial work orders outstanding

12. Yellow sheets

13. Preflight inspection sheets

14. Periodic inspection sheets

10-13. AIRFRAME. The airframe log books and records should reveal the following information to the investigator.

1. Date of acceptance by Navy

2. Number of overhauls or PAR's

3. Overhaul activity

4. Time since last overhaul or PAR

5. Date of last inspection

6. Service changes and bulletins outstanding

7. Serial or work orders outstanding

8. Preflight inspection forms

9. List of pilot discrepancies from yellow sheets of previous flights

10-14. OTHER RECORDS. These pertain to aircraft, maintenance, and service procedures:

1. Oxygen

2. Radio

3. Refueling facilities

4. Parachute

5. Ejection seat

10-15. AEROMEDICAL RECORDS.

10-16. As the complexity of military flight operations increases, there is an increasing awareness of the involvement of aeromedical aspects in accident investigation. While this is the domain of the flight surgeon and is one of the major reasons he is assigned to the aircraft accident board, the senior member should acquaint himself with the aeromedical factors in general and insure that the assigned flight surgeon has the full cooperation of all the members in receiving and making use of his specialized knowledge that will make for a complete investigation in this area. Some of the records that the flight surgeon will review during the investigation are:

1. Flight crew medical record

2. Oxygen training

3. Ejection seat training

4. Night vision training

5. Personnel records to establish social and economic relations and other personal factors.

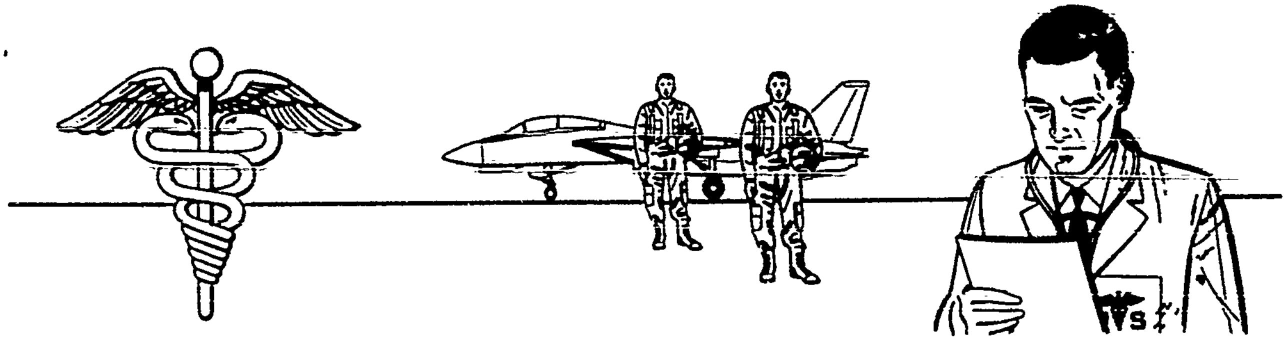
10-17. WEATHER RECORDS.

10-18. In general, such items as temperature, dew point, humidity, cloud cover, and visibility at the time and place of the accident will be included in every accident report. They should be recorded regardless of the apparent effect on the accident in question. In weather accidents, all available weather information which is pertinent will be furnished with the report, together with the weather officer's signed analysis of it. His analysis should also explain if the weather was as forecast, and, if not, the reason for the discrepancy. In every case where it appears that inaccuracy of weather forecasting is a factor in the accident, all considerations should be given in detail.

10-19. When pertinent to a particular investigation, weather maps, weather sequences, synoptic charts, upper-air observations, pilot reports, eyewitness accounts, and statements of survivors which show the weather throughout the flight constitute important evidence. When these aids are not available for territory adjacent to the accident scene, fairly reliable weather information may be obtained from local weather bureau observers, forest lookouts, forest rangers, fire wardens, highway patrolmen, or local residents. Information thus obtained may be coordinated with the authentic information from the local weather office in the preparation of required statements.

10-20. ANALYSIS OF RECORDS.

10-21. When records are being reviewed by the assigned task groups, it will be difficult to commit all the data that may be pertinent to memory. It will oftentimes also be difficult to have the originals of all the records available at one time and place to review when the board is in formal session to arrive at the conclusions and recommendations. It is suggested that the information and data extracted from the records be comprehensively compiled and integrated as much as possible prior to the analysis phase. This will enable the board to refer to the data with ease and accuracy.



CHAPTER 11

AERO-MEDICAL

11-1. FLIGHT SURGEON'S INVESTIGATION.

11-2. OBJECTIVE OF FLIGHT SURGEON'S INVESTIGATION. The primary purpose of the flight surgeon's participation in an aircraft accident investigation is to determine and weigh the importance of human factors involved in the aircraft accident. This will necessarily involve a thorough and detailed investigation of the pilot from the biological and sociological standpoint, investigation of the effectiveness of the protective equipment, clothing utilized, and so forth. The majority of aircraft accidents involve a breakdown of one or both of the two complex machine systems working together; the aircraft and its systems or the pilot and his systems. The flight surgeon is responsible for the investigation of the latter in its entirety. Since this job involves investigating a much more complicated machine, his task is very difficult.

11-3. The flight surgeon, through his specialized training, contributes a key part to the deliberations of the aircraft accident board of which he is a member. The very same close observation and attention to details which are constantly stressed throughout a flight surgeon's education and enable him to establish a diagnosis in a difficult medical or surgical case are the identical ones which must be brought to bear on every accident to determine similar etiological factors. Accident investigation is essentially a difficult differential diagnosis problem. The painstaking detail involved in attempting to evaluate the physical, emotional, training, or human engineering design factors underlying the majority of aircraft accidents cannot be overestimated. Their ultimate exploitation will depend on the ingenuity of the accident board flight surgeon. Attention is directed to the aeromedical section of the Aviation Safety Officer's Guide for additional information regarding the role of the Flight Surgeon in aviation safety.

11-4. The statistical data compiled at the Naval Safety Center clearly indicates the "human element" as being that area in which the greatest contribution can be made toward reducing aircraft accidents. Approximately 50 percent of our present accidents fall within this group. A major responsibility for accomplishing a reduction in the number of accidents within this category rests with the flight surgeon, since this type of accident deals primarily with those factors in which he has received the greatest amount of scientific and professional training. He is, therefore, capable of estimating the performance efficiency of the human machine and the role it has to play.

11-5. The successful accident investigation is the result of the completely integrated team effort of the accident board members with a pooling of their specialized talents and abilities. It involves pathological and material laboratories, photography, interrogation of witnesses, detailed investigation of the scene, a reconstruction of the entire situation, and so on. Each piece of evidence must be carefully weighed and its contribution proven or disproven, until the entire picture of the accident is recreated and the causal factors exposed. The specific cause can and must be found for every accident if lives and money are to be saved. While it is relatively easy to assess the importance of a failure in the electrical system in a single accident, it is at present difficult to similarly assess, from reports, the importance of the pilot's reactions in an accident situation. However, if real progress is to be made in determining the role of pilot factors such as these and many others similarly related to pilot efficiency, they must be thoroughly investigated and reported in each and every accident.

11-6. PRE-ACCIDENT PLANNING. Of prime importance is insuring that the necessary medical equipment is available for answering a crash alarm. The following questions should be answered prior to a crash:

1. Does the station crash bill clearly set forth the responsibilities of the medical department?

2. Does the medical facility have a crash bill?

3. Is the medical facility placed on an alert basis and is it prepared to receive injured or dead shortly after the crash alarm has been sounded?

4. Is the ambulance driver aware of his position in the crash vehicle convoy? Is he familiar with the grid map and routes to the various outlying areas?

5. Does the crash ambulance contain the necessary material such as an emergency treatment bag, pathology kit containing syringes for drawing blood samples, storage containers and shipping containers for blood and tissue, rubberized remains pouches, personal effects bags, blankets, oxygen, splints, dextran, etc.?

6. Have arrangements been made with the local civilian agencies, especially the local coroner, to permit expeditious handling of remains of military personnel by military authorities? Ideally, arrangements should be made to notify him by telephone and to furnish him a copy of the death certificate.

7. Have the local laboratories been contacted for possible assistance? These include State toxicology laboratories, other service hospitals and pathology centers, naval hospitals, etc. Are facilities and personnel prepared to perform autopsies, collect, package, and ship biological specimens?

8. Is at least one AVT trained in the requirements of crash investigation, the necessary reports, etc.?

9. Is a check list handy to insure completion of all required items at the scene of the crash?

This is by no means a complete list of preparations required. Much of the planning will necessarily come with experience and the special problems inherent to the operating unit and conditions. Thorough precrash planning, however, can substantially lessen the workload imposed by an aircraft accident investigation. Such preparation may well mean the difference between a successful and an unsuccessful investigation.

11-7. AT THE SCENE. The first duty of the flight surgeon investigating officer on reaching the scene of the crash is to render the necessary medical assistance to the persons who are injured. H should, because of his training and experience, supervise the treatment and handling of personnel being removed from the aircraft to prevent additional injury.

11-8. If the crashed aircraft is afire, the flight surgeon and medical attendants should render every assistance possible. Generally, when the aircraft is burning, the crash crew will remove the personnel from the aircraft since they are both equipped and trained to do so.

11-9. One of the primary responsibilities of the flight surgeon to the accident investigation is to survey the casualties involved quickly and notify the base medical facility, which should now be on an alert basis. This will permit medical personnel to take the necessary steps to receive the casualties or to cancel the alert.

11-10. Immediately after noting position of the injured and evident cause of injury, administering necessary treatment, and supervising removal of injured personnel, the medical officer should begin his detailed study of the accident. The wreckage should be disturbed as little as possible in the process of removing personnel. Bodies of personnel found to be dead should be covered and left where they are found for the period required to make photographs or sketches, and other investigations. Sketches and photographs should be made so as to include the location of the wreckage and position of each body in relation to it. These will be useful not only in identification but also in the accident investigation. After this has been accomplished, fatally injured persons should be placed in rubberized remains bags. The exact location of the body or parts should be marked and identification tags placed on markers as well as on the pouch in which the remains are placed. A thorough search of the area surrounding the body should be undertaken by a search party in order to locate all parts of the body, equipment, and personal belongings. An emergency treatment tag, with appropriate notations should be tied to each body. Bodies should be identified by number until definite identification can be established.

11-11. As far as possible, every effort should be made to complete identification at the scene, as the position of the bodies and other factors in relationship to the scene are reliable clues. Once death has been established and before a body is disturbed, the immediate area should be searched for identification tags, rings, jewelry, watches, etc., especially if the body has been burned. Parachute harness and clothing should be removed bit by bit, and each fragment carefully examined.

11-12. PUBLIC RELATIONS. It is important that no information regarding the identity of the victims or the nature of the casualties be released to the press or to any unauthorized civilians except by a public information officer or in accordance with the instruction governing aircraft accident reporting procedures, OPNAVINST 3750.6 series.

11-13. PERSONAL EFFECTS, MESSAGES, ETC. The medical officer has certain responsibilities for insuring that administrative requirements are met in sending the required message reports, disposing of personal effects, etc. These are all covered in instructions listed at the end of this chapter.

11-14. PROCESSING REMAINS. In general, the district medical officer should be consulted on any problems in the handling of remains. Funds are available for the recovery of remains, if it is necessary to employ civilian equipment or labor. Thus if a pilot is in the cockpit of an aircraft in shallow water, the flight surgeon may, through the district medical officer, secure civilian equipment to recover the body. In many cases it may be necessary to recover the body before tissue change has destroyed the evidence which might be revealed through histopathological investigation.

11-15. NECROPSY. The flight surgeon shall recommend to the commanding officer that an autopsy be performed on all aircrew members who sustain fatal injuries in aircraft accidents. Autopsies should be recommended on other personnel aboard when circumstances indicate toxic agents, illness, decompression, etc., or when the specific cause of death is not known.

11-16. In conducting the gross autopsy, the services of an experienced pathologist, either military or civilian, are indicated. The flight surgeon should assist, however, and be prepared to lead the inquiry along lines that will yield the required aeromedical information. Under certain conditions the flight surgeon may be required to conduct the autopsy. The publication, Autopsy Manual (see paragraph 11-29), is available to flight surgeons and medical officers as a guide in performing post mortem examinations. Refer to the current BUMEDINST 6510 series for services provided by the Armed Forces Institute of Pathology and by the Histopathology Center in the geographical area concerned. Flying personnel are being subjected to environmental factors new to medicine, and fatalities occurring as a result of their effects on the human organism are of particular interest to the pathologist as well as the investigating flight surgeon.

11-17. TISSUE ANALYSIS. If specimens are to be forwarded to central facilities such as the Armed Forces Institute of Pathology the procedure must be outlined in advance to insure success.

1. Frozen Tissue. Freezing techniques are used for the preparation of sections for immediate diagnosis, for certain histochemical procedures, and for materials required in toxicological studies. Toxicological examinations are performed at the Armed Forces Institute of Pathology only in cases of aircraft accidents. Prompt collection of fresh tissue is essential, in order to protect it against chemical or mechanical change. Chemical preservations invalidate results of toxicological analysis; therefore, no fixing fluid (formalin) should ever be used, and formalin-fixed tissue should never be packed in the same container with frozen material. Refrigeration (dry ice) is the prescribed method of preservation, and rapid transportation is of the utmost importance.

2. Toxic Agents. In completing gross autopsy protocol (DD Form 1322), when toxicological studies are requested, it is important to indicate any suspected intoxicants or drugs. Every medical officer investigating an aircraft accident must be alert to the possible presence of toxic agents. Toxic substances most often encountered are carbon monoxide, alcohol, and drugs.

a. Carbon monoxide levels in the blood are considered normal for the purpose of aviation pathology if below 10%. Levels above this value indicate that the individual was exposed to the products of combustion, either before or after the accident. Hemoglobin has approximately 200 times the affinity for carbon monoxide it has for oxygen. The degree of poisoning by CO determines the results which may range from headache, nausea, dizziness and mental confusion to asphyxial death. Table 11-1 illustrates the conclusions which can be drawn from carbon monoxide level in the blood. Whole blood is the best specimen for examination but any tissue which contains a considerable amount of blood such as liver and lung can be used. Even when extensive burns occur, it may be possible to obtain satisfactory blood specimens from areas such as the chambers of the heart or deep within the liver and the lungs.

b. Alcohol quantity is reported as the number of weight units of alcohol per 100 weight units of specimen thus giving the percent

Table 11-1. Value of Carbon Monoxide Studies

	FINDINGS	MEANING
1.	CO elevated instantaneous fatal injury –	CO inhaled prior to impact indicating inflight fire or other source of CO
2.	CO not elevated instantaneous fatal injury –	CO not a factor in the accident
3.	CO elevated No instantaneous fatal injury	If no post crash fire, probable means individual breathed CO inflight. If post crash fire, probable means individual breathed CO after impact.
4.	CO not elevated No instantaneous fatal injury –	CO not a factor in the accident

of alcohol in the specimen. For example, a result reported as 0.10 percent means each gram of specimen contains 1.0 milligrams (0.001 gram) of alcohol. The presumptive limits in table 11-2 are generally recognized as legal standards in establishing whether or not an individual is intoxicated. Recognize that these are legal limits and do not necessarily reflect the level at which degradation of performance occurs. Several studies have shown that deterioration of performance in driving tests has occurred with levels as low as 0.03 percent. The best specimens for alcohol determination are blood, stomach contents, urine, brain, kidney and liver. Careful attention must be given to avoiding contamination of specimens with alcohol from some other source (i.e., deicing fluid, containers previously used or cleaned with alcohol, etc.). It must be remembered that small quantities (up to 0.08%) of alcohol can be produced in tissues by putrefaction. Therefore, the condition of the specimen must be taken into consideration before reaching the conclusion that the individual had ingested alcoholic beverages in sufficient time prior to the accident to have a positive result. A generally accepted fact is that the average individual metabolizes (burns up) 0.4 ounces of 100% alcohol an hour. This is roughly equivalent to an ounce of 100 proof whiskey. The blood alcohol level drops approximately 0.02% per hour. For example, if originally 0.18%, it will be 0.16% one hour later.

c. Drugs of certain classes are incompatible with the functions required of aircrew members. Some examples are antihistamines, tranquilizers, barbiturates and other "sleep" inducing drugs. Many antihistamine and sleep inducing drugs are available as non-prescription items and can be purchased widely. Drug studies are time consuming procedures but even if the suspicion is entertained that a drug(s) may have been a factor in an accident, then the flight surgeon should request the necessary tests. The laboratory conducting the tests should be informed of the type or general class of drug(s) suspected. A request for "drug studies" is almost without meaning, for with the thousands of drugs available, the toxicologist hardly knows where to begin. The best specimens for drug studies are blood, brain, kidney and liver.

Table 11-2. Legal Standards of Intoxication

% of Alcohol		Condition
0.05 or less	–	presumed to be uninfluenced
0.05 to 0.10	–	possibly influenced
0.10 to 0.15	–	probably influenced
0.15 or more	–	presumed to be under the influence

3. Preparation and Packing of Specimens. Tissue specimens for toxicological examination will be collected under the supervision of the pathologist performing the autopsy and will consist, whenever possible, of the following: liver, brain, kidney, lung, bone marrow, blood, urine, and stomach contents. Precautions should be taken to prevent contamination of the specimen during the course of the autopsy. Thorough toxicological examination requires approximately 250 to 500 grams of brain, liver, kidney, and lung, 100 ml of blood, and all urine available. The amount of tissue available will govern the amounts submitted. Red bone marrow and lung tissue are especially useful in such cases where disintegration of the soft tissue has occurred.

a. Individual tissue specimens, that is brain, liver, etc., should be placed in separate plastic bags. In view of the quantity of material required, it may be necessary to distribute the individual specimens between several latex rubber or plastic bags.

b. Blood and body fluids will be shipped in latex rubber bags. The air should be carefully evacuated prior to closing the bag by knotting or other means. As an added precaution, this type bag should be enclosed in a second bag.

c. It is recommended that heavy polyethylene plastic bags (.005 or .006 gauge) or latex rubber bags (condoms) be used as individual specimen containers. The specimen should be placed in the plastic or rubber bag, as much air as possible evacuated from the bag, and the bag then heatsealed, knotted, or securely fastened with a rubber band. As an added precaution, the tissue should be enclosed in a second bag in which a tag with all identifying data should be placed. It is recommended that only paper labels be used in identifying frozen specimens, as plastic labels may cause camphor odors to permeate the specimens and give false determinations. Heat-seal or fasten the second bag, as indicated above, and prepare for shipment. DD Forms 1322 (Aircraft Accident Autopsy Report), 1323 (Toxicological Examination - Request and Report), and any other available information should be sealed in a separate plastic bag and forwarded along with the specimen.

d. It is imperative that frozen specimens and dry ice not be packed in sealed cans or any type of container which will not permit the escaping gas to pass through its walls. Dry ice is formed under tremendous pressure; it requires approximately 230,000 cc of carbon dioxide under pressure to form one pound of dry ice. The pressure created inside a sealed container presents a great potential hazard, as it could cause the container to burst. Do not enclose dry ice in a thermos bottle unless holes are drilled through the stopper of the thermos.

e. When packing for shipment, the specimen and protocols (DD Forms 1322 and 1323) should be placed in a stout cardboard box filled with pieces of dry ice and enough filler (sawdust, styrofoam, etc.) to fill and insulate the box. The box should be large enough to hold eight to ten pounds of dry ice for a shipping time of 24 to 36 hours, and should be sealed with tape, then wrapped in several layers of heavy paper. A plastic-insulated box is available on the Federal Stock Schedule.

4. Addressing. The packing box containing specimens for toxicological examination should be labeled "FRAGILE – RUSH – SPECIMENS FOR TOXICOLOGICAL EXAMINATION (AIRCRAFT ACCIDENT)." and forwarded by military or commercial Air Freight to the Director, Armed Forces Institute of Pathology, Washington, D.C. Correct designation should be clearly written to insure prompt delivery. Send TWX notifying AFIP of 1) time of arrival, 2) airline, 3) flight number and airport. Also put telephone number at AFIP on outside of package and ask carrier to call when material arrives. Mark "Frozen Tissue" on package, as well as the above "Fragile, etc."

WARNING

Dry ice should not be handled without the use of gloves, and should not be placed in glass or other completely "closed" containers. Do not enter poorly ventilated areas where large quantities of dry ice are stored.

5. Time Table for Frozen Specimens. A suggested table has been prepared for guidance of personnel in preparing fresh tissue specimens being shipped for use in toxicological studies. Table 11-3 gives the estimates for outside temperature and the number of hours in transit. This will assure that sufficient dry ice will be used to protect the specimen until its arrival at the final destination.

11-18. After all bodies have been removed from the scene of the accident, the autopsies have been performed and the specimens have been shipped, the flight surgeon investigator should assume his duties as a member of the aircraft accident board and the task group to which he has been assigned. As such, the flight surgeon member will make his contribution both as a working member and as a specialist whose training and experience should make him one of the most valuable members of the board. Pilot-caused accidents are truly the flight surgeon's domain. Naval Safety Center experience shows that a special effort will be required to avoid making a snap diagnosis as to material factor or human factor. The flight surgeon should direct his efforts toward establishing facts and not attempting to justify unsupported theory

11-19. THE AEROMEDICAL TASK GROUP. As a member of the aircraft accident board, and leader of the aeromedical task group, the flight surgeon has the responsibility to investigate the pilot's sociological, psychological, and physiologi-

Table 11-3. Time Table for Frozen Specimens

Outside Temperature	No. Hours in Transit	Weight of Specimen	Minimum Amount of Dry Ice Add More When Possible
Below 50 Degrees F	72	2 lbs.	5 lbs.
	48	3 lbs.	4 lbs.
	24	4 lbs.	3 lbs.
50-80 Degrees F	72	2 lbs.	5 lbs.
	48	3 lbs.	4 lbs.
	24	3 lbs.	4 lbs.
80-100 Degrees F	72	1 lbs.	6 lbs.
	48	2 lbs.	5 lbs.
	24	3 lbs.	4 lbs.
Over 100 Degrees F	(Not recommended for shipments requiring more than 24 hrs.)		
	48	1 lbs.	6 lbs.
	24	2 lbs.	5 lbs.

cal background for factors which may have caused or contributed to the accident as well as to investigate the adequacy and functioning of safety and survival equipment in the crash and postcrash situation. It is impossible to cover in this chapter all those factors which should be thoroughly explored. The criterion must be - **Check and Report Everything**, making use of all the ingenuity you possess.

11-20. Sociological, Psychological, and Physiological Factors. There are two general approaches which must be made to the investigation of these elements in an aircraft accident. The first involves a reconstruction of the situation which confronted the pilot and resulted in the accident. The second, the background approach, includes gathering all the material on the pilot's background antedating the accident which might explain or clarify the actions or mistakes he made which resulted in this accident.

11-21. Neither of these is simple. The first will be easier if the pilot is still alive and can be induced to repeat in minute detail everything that happened just prior to and during the accident situation. Without the pilot to interview, the reconstruction is difficult but is generally made possible by the gathering together of a mountain of minutiae. This will include everything from the pilot's financial difficulties, to transmissions he may have made, to the position of his body, to instrument readings. Although incomplete, bits of evidence and even hypotheses accumulated over a series of accidents will eventually show results. An example of the salient points which should be covered follows.

1. Total experience, experience in type of aircraft, experience in type of flight or maneuver undertaken, possibility of training interference, etc. Establish a rough measure of the confidence and ability which the pilot might have had.

2. Physical situation at time of accident, i.e., weather, altitude, pressurization and temperature conditions, oxygen use, etc. Establish a measure of the physical environment.

3. Emergency conditions or warnings existing, such as lost, out of control, fire, loss of instruments, low fuel, other aircraft in area, communications, etc., establish a measure of the immediate stress on the pilot.

4. Determine the number of hours of duty and sleep in the last 24 hours, visual acuity, auditory acuity, reaction time, blood chemistry,

alcohol as involved, etc., to get a measure of the physical condition of the pilot or his ability to withstand stresses.

5. Find evidence as to pilot's emotional tone at time of the accident, i.e., anxiety, anger, frustration, etc., to get a measure of the pilot's mental state imposed by stresses. Interview the pilot's family, friends and colleagues thoroughly.

6. Check the personality structure of the pilot, i.e., determine the expected reaction of the pilot under the conditions imposed by items 1 through 5 above.

7. Review the cockpit again, in view of the above analysis, and determine whether the cockpit layout might have been involved, whether or not a modified control or location or information presentation might have prevented the accident or permitted the pilot to handle the situation.

11-22. This is but a brief coverage of the items involved, but should present an idea of the thoroughness which is required to find the causal factors. Always remember that a piece of evidence, while negative on primary cause, may be the essential evidence in another area. For example, a blood sample may not appear relevant in what appears to be a material-failure accident. However, its analysis for toxic substances, blood chemistry, drugs, etc., may be final evidence to prove that this was a pilot-induced material failure, i.e., that considering the stress imposed, the personality structure of the pilot, and layout of the cockpit, the accident was "pre-determined." In a similar manner, the presence of, for example, pharmacological agents in the blood will offer an invaluable clue both as to the problems which the pilot was fighting and physiological condition level at which he was operating at the time of the accident. Here is a clue as to his overall efficiency.

11-23. The entire process of accident investigation is a differential diagnosis. The flight surgeon, of all the accident board members has had special training in this process. In clinical medicine, one life may be involved; but in aviation accidents, possibly hundreds of lives, and millions of dollars may depend on the thoroughness of your diagnosis.

11-24. THE AIRCRAFT ACCIDENT REPORT. [A] significant finding is worth only as much as the results it produces. In the case of accidents, the information must be placed in the hands of agencies which can take remedial action. Thus a report of the findings of the accident board is essential. As in medicine, an unsupported diagnosis itself is not only inadequate but dangerous. The entire clinical history, laboratory findings, special consultants, etc., are needed. Similarly, in accidents, the entire picture or story is needed.

11-25. When laboratory reports or autopsies are not available within the time requirements of reporting, forward them as soon as they are available. Do not delay the basic report. In the same manner, do not hesitate to forward modifications or reversals of findings. The determination of the cause of some accidents is an elusive and difficult task requiring many days of hard work. The investigation and reporting of an aircraft accident requires the accumulation and submitting of this information.

11-26. Do not hesitate to ask for assistance. Th[e] following activities and references are sources o[f] further information.

11-27. Useful phone numbers are:

1. Naval Safety Center – Commercial 703-444-3321, Autovon 8-690-3321. After working hours call Commercial 703-444-3520 or Autovon 8-690-3520.

2. Armed Forces Institute of Pathology – Commercial 202-723-1388 or 202-576-3232. Autovon 8-346-3232 or 8-346-2800.

11-28. Useful references are:

1. BUMEDINST 6510 series.

2. OPNAVINST 3750.6 series.

3. NAVMEDP-5083, Methods for Preparing Pathological Specimens for Storage and Shipment.

4. NAVMED P-5065, TM8-300, AFM

160-19; Autopsy Manual.

5. BUMEDINST 5360. 1 series; Decedent Affair Manual.

6. MANMED Art. 17-18.

7. U.S. Naval Flight Surgeon's Manual.

8. JCAP Memorandum No. 1, AFIP, Washington, D. C.

9. Aviation Safety Officer's Guide

APPENDIX A.

AN ACCIDENT INVESTIGATOR'S EQUIPMENT

A-1. INTRODUCTION.

A-2. To start the investigation as quickly as possible, the investigator and his team must be properly equipped. Accidents are rarely confined to any particular area. Therefore, the investigator should be prepared to conduct his investigation in spite of any hardships which might be encountered due to terrain, extremely hot or cold weather, or any other conditions which may occur.

A-3. CLOTHING.

A-4. It is nearly always necessary to crawl around or under aircraft wreckage, so the investigator should arrive at the scene appropriately clothed. Comfortable working clothes of the correct weight for the existing weather, which the investigator does not mind soiling, should be worn. To protect your hands against cuts and infection while handling broken metal parts, be sure your clothing equipment includes a pair of heavy working gloves. These gloves are a necessity. In short, don't show up at an accident scene in a dress uniform and expect to get the job done.

A-5. FIELD KITS.

A-6. The type of equipment to use on investigations cannot be standardized due to differences in terrain, aircraft type, location, etc. However, certain basic items usually are necessary in most situations. The following is a list of basic items which should be included in all field kits. (See table A-1.)

1. A good magnetic compass
2. A steel measuring tape (50 to 100 feet)
3. A protractor
4. A draftsman's scale
5. Writing material and notebook
6. Graph paper
7. Shipping tags (for identifying parts)
8. Containers suitable for fuel and oil samples
9. Suitable hand tools for removing small parts, drain plugs, instruments, etc.
10. Flashlight and spare bulbs and batteries

Table A-1. Investigator's Kit Inventory List

Case #1		Case #2	
Description	FSN	Description	FSN
8415-268-7868	Gloves, leather	5110-228-3161	Hatchet, half
~~8415-261-4771~~	~~With wool inserts~~	5110-721-6810	Folding 3-bladed knife
7510-243-3439	Rubber bands	1095-392-4102	Survival knife "K" bar
4720-968-1357	Plastic tubing	5120-270-4309	Wrench, pipe, 3 1/2"
8105-290-0335	Small plastic bags	5120-264-3796	Adjustable, open end wrench
7510-223-6690	Chalk	5120-240-5328	Adjustable, open end wrench
8135-178-9200	Shipping tags	5120-059-6711	Parrot nose serrate jaws
7510-223-6690	Grease pencils - Black	~~5120-278-0351~~	~~Common pliers~~
7510-223-6691	Grease pencils - Blue	5110-243-0901	Hacksaw blades (10)
7520-633-8718	Grease pencils - Green	5120-227-7362	Flat tip screwdriver, Heavy duty,
7510-174-3205	Grease pencils - Red		12" x 3/8"
7510-281-5234	Colored pencils - Black	5120-293-0314	Flat tip screwdriver, normal
7510-223-2027	Colored pencils - Blue		duty, 10" x 1/4"
7510-264-4610	Colored pencils - Green	5120-517-8099	Flat tip screwdriver, normal
7510-233-2021	Colored pencils - Red		duty, 8" x 1/4"
6650-514-3531	Magnifying glass	5120-724-3766	Phillips screwdriver, heavy duty,
7510-161-6215	12" Ruler		10"
6675-238-3498	Draftsman's ruler	5120-988-6490	Flat tip screwdriver, 6" x 3/16"
7530-222-0078	Small notebooks	5120-596-1183	Flat tip screwdriver, light duty,
7510-281-5234	Pencils		r" x 1/8"
7530-223-7898	Graph paper 8" x 10"	5120-596-0866	Reed & Prince, 3" x 3/16"
7530-285-3068	Plain paper	5120-278-1273	Flat tip screwdriver, 1 3/4" x
7530-285-3083	White line paper		5/16"
	Handbook for Aircraft Accident	5120-227-8173	Flat tip stubby screwdriver,
	Investigation (NAVAIR 00-80T-67)		1 1/2" x 1/4"
6545-664-5313	First aid kit	5110-239-8253	Heavy duty diagonal cutting
6545-551-8344	Snake bite kit	5110-224-1532	Light duty diagonal cutting
6230-270-5419	High intensity light (2 oz.)	5120-203-7064	Short series wrenches (10)
6530-406-0150	Bottles (Duraglass), 1 dozen	5110-289-9657	Hacksaw frame
	2' x 2' Flags, 1 dozen (locally	5120-618-6902	Inspection mirror
	produced, highly reflective)	5120-180-0873	Crowbar
	3' Stakes (welding rod), 1 dozen	6230-270-5418	Flashlight
	Tape recorder, cassette type	6135-020-1020	Flashlight batteries (4)
	(locally purchased)	6240-155-8675	Flashlight bulbs (8)
8405-290-0550	Poncho, corted nylon	5210-221-1882	100 ft of metal tape
7210-282-7950	Blanket, bed, green	4020-968-1357	100 ft of rope with loops at
8465-255-8223	Packboard		every 10'
		8405-290-0550	Poncho, corded nylon
		7210-282-7950	Blanket, bed, green
		8465-255-8223	Packboard

11. Pocket lens (magnifying glass)

12. Marking crayon (grease pencil)

13. Snake bite kit (if applicable)

14. Camera and flash bulbs (in case a photographer is not available)

15. Insect repellent (if applicable)

A-7. This equipment (or that which is found to be most suitable for the particular locale) should be assembled in kit form and taken to the accident scene immediately. The kit shown in figures A-1 and A-2 consists of two containers, each constructed from a packboard, leatherette, bungee cord, and velcro tape. The kit contains all of the necessary items in a form convenient for carrying in most types of terrain.

A-8. A secondary kit containing heavier equipment and items needed for more detailed examination of the wreckage should be available to the investigator. This kit should include technical orders pertinent to the aircraft, maintenance instruction manuals, handbooks of operating instructions, parts breakdowns, and whatever other equipment the investigator finds that he needs.

A-9. Before entering the accident scene the investigator should anticipate his needs for special equipment such as skis, food, water, axes, a guide, pack horses, or whatever else the locale requires.

A-10. It must be emphasized that the inclusion of proper equipment as a part of the pre-accident plan is of the utmost importance. Valuable evidence may be destroyed while the investigator scurries around the installation trying to assemble his equipment after the accident has occurred. Have the equipment assembled in kit form readily available.

A-11. WRECKAGE RECOVERY EQUIPMENT.

A-12. In all probability the investigator will arrive at the accident scene shortly after the accident. In addition to the tasks previously mentioned, he should ascertain the type of wreckage recovery equipment that will be required to do the job with minimum damage to the wreckage. If the accident is the "hole-in-the-ground" type, a bulldozer and clamshell will be required. It may be necessary to have pumps available to remove water from the hole. Flat-bed trucks will be needed to remove the wreckage from the scene. If the aircraft is not broken up, equipment capable of lifting heavy components will be needed. Ascertaining at an early stage the equipment requirements, and active participation and supervision of the recovery operation are vital tasks to the investigator. He must be familiar with the equipment that is available at his base. If the scene of the accident is distant from the parent base, a nearby naval or marine facility will be responsible for

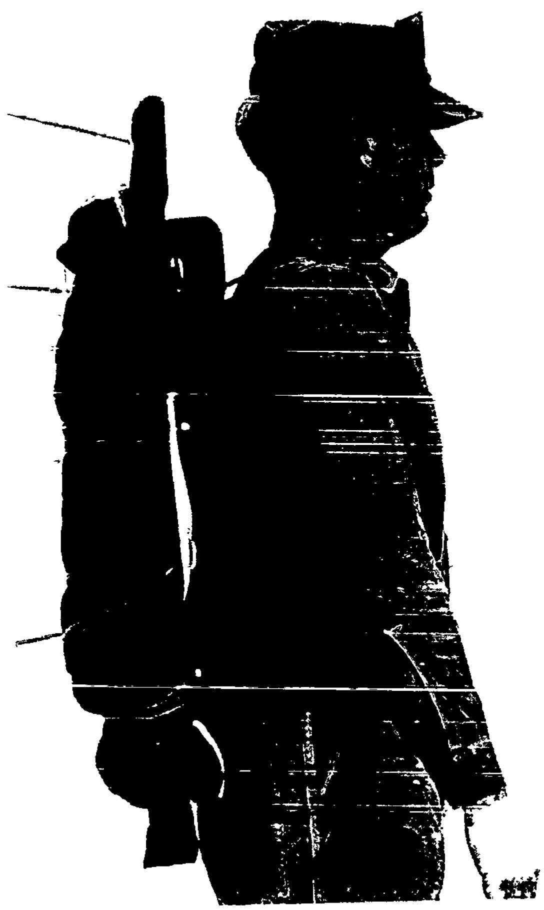


Figure A-1. Investigator's Kit

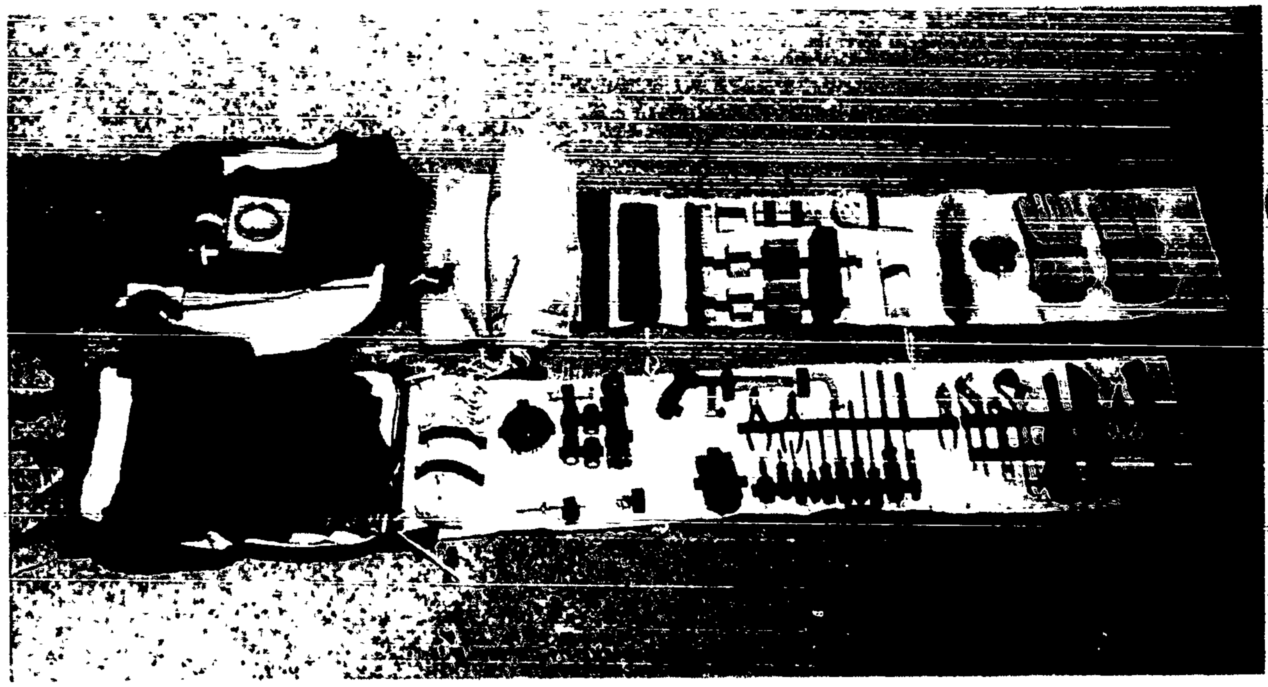


Figure A-2. Investigator's Kit

and designated as the recovery activity. Early determination of the equipment requirements will assist in the arrival of the proper tools to do the task. The investigator has a responsibility in the recovery operation regardless of the activity designated to do the work.

A-13. If the aircraft is in the water, suitable equipment for detection, marking, and removing the wreckage will be required. It may be that hand-held sonar, divers, or mine-detecting equipment may be required. Usually the local naval district headquarters, ComFair, or type commander can arrange for the provision of the necessary equipment. However, the investigation should decide what is required and request it from the appropriate superior command.

APPENDIX B.

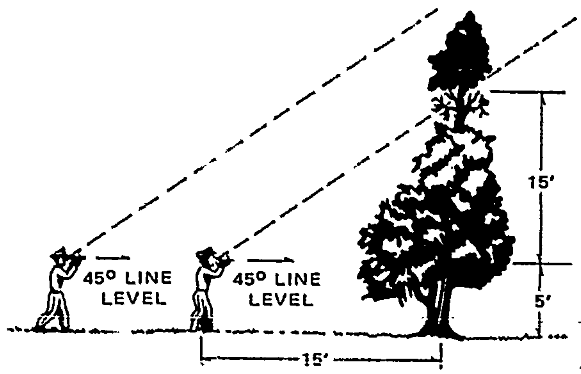
ANALYSIS OF PHYSICAL EVIDENCE AT THE SCENE OF THE ACCIDENT

B-1. GENERAL.

B-2. Information on maneuvers just prior to the accident is valuable in estimating the angle of impact and speed of the plane at impact. Whenever a plane hits an obstruction, the approximate height of the point where the plane struck should be obtained. In cases in which a plane goes out of control near the ground and spins or spirals into the ground, an estimate of the altitude at which it went out of control is valuable. This is sometimes difficult since witnesses who are not pilots often give erroneous and conflicting altitude estimates. For purposes of comparison, 100 feet is the height of an average 8- to 10-story building. A 45-degree sightline can be used to find the height of objects by triangulation (see figure B-1).

B-3. OBSTACLES AIRCRAFT HIT BEFORE FINAL IMPACT.

B-4. Striking wires, trees, and other obstacles at flying speed will usually absorb a good deal of energy and slow down a plane prior to the principal impact. Information as to what part of the plane hit the obstruction will give an indication of the forces imposed upon various parts of the plane and sometimes will indicate the direction in which the occupants were thrown.



HOW TO FIND APPROXIMATE HEIGHT OF OBJECTS

1. Hold card vertically as shown; tilt card up or down until 45° line is level.
2. While holding 45° line level, walk toward or away from object until it lines up with edge of card.
3. From this point, pace off or measure distance to base of object. A pace (two steps) is approximately 5 feet.
4. Add 5 feet to measured (or paced) distance to get approximate height of object.

Figure B-1. Finding Approximate Height of Objects

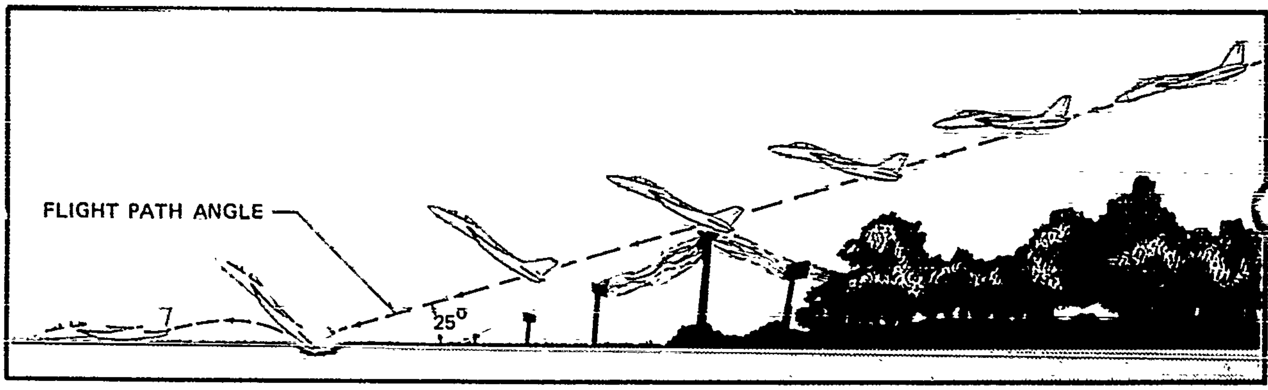
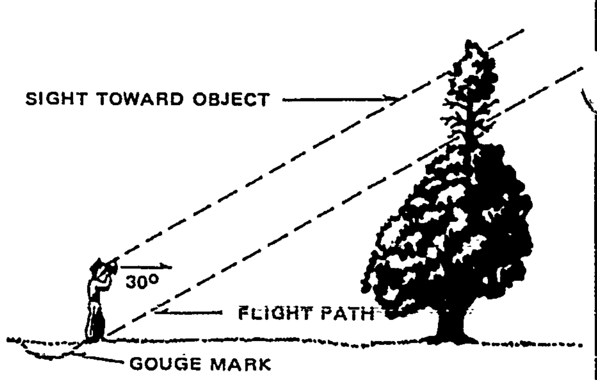


Figure B-2. Definition of Flight Path Angle

B-5. ESTIMATING FLIGHT-PATH ANGLE OF AIRCRAFT. The flight-path angle of an aircraft is the angle between the flight-path and the horizontal. The flight-path angle of the aircraft as it descends toward the ground may be quite different from the angle of the longitudinal axis of the aircraft with the horizontal. Just before hitting an object, the plane may be pulled up into a nose-high attitude to avoid collision but may continue to mush downward toward the ground (see figure B-2). The flight-path angle is of interest in determining how much energy is absorbed prior to the final impact. In many cases this angle will not be known and considerable difficulty will result in estimating it. Sighting from the point of first ground impact to the damaged obstructions or objects will often help in estimating the flight-path angle (see figure B-3).

B-6. ESTIMATING ANGLE OF IMPACT OF THE AIRCRAFT. The angle of impact is the angle between the flight-path of the aircraft and the surface of the terrain. In open-sea landings, the angle will depend upon the point of contact with the swell. The angle of impact is of interest in determining the amount of energy absorbed on the final impact. The angle of impact may be quite different from the angle of longitudinal axis of the aircraft with the surface. For example, a plane may be tripped by catching its landing gear on a tree or wire so that it strikes the ground vertically on its nose (see figure B-4). When impact is made with a horizontal surface, the angle of impact and the flight-path angle are the same (see figure B-5). An aircraft descending and hitting on a downhill slope (or down swell) as in figure B-6 has a very different angle of impact from that of an aircraft hitting on an uphill slope (or up swell) as in figure B-7, even though their flight-path angles may be the same. An aircraft with a horizontal flight-path angle striking a vertical surface has an impact angle of 90 degrees (see figure B-8).



HOW TO FIND APPROXIMATE FLIGHT PATH ANGLE

(When Aircraft Has Struck and Damaged Objects)

1. Hold card as instructed and sight along edge of card toward object at a point approximately 5 feet above damaged area.
2. While holding card as described above, look toward horizon and read number (degrees) on whichever line appears to be level.

Figure B-3. Finding Approximate Flight Path Angle

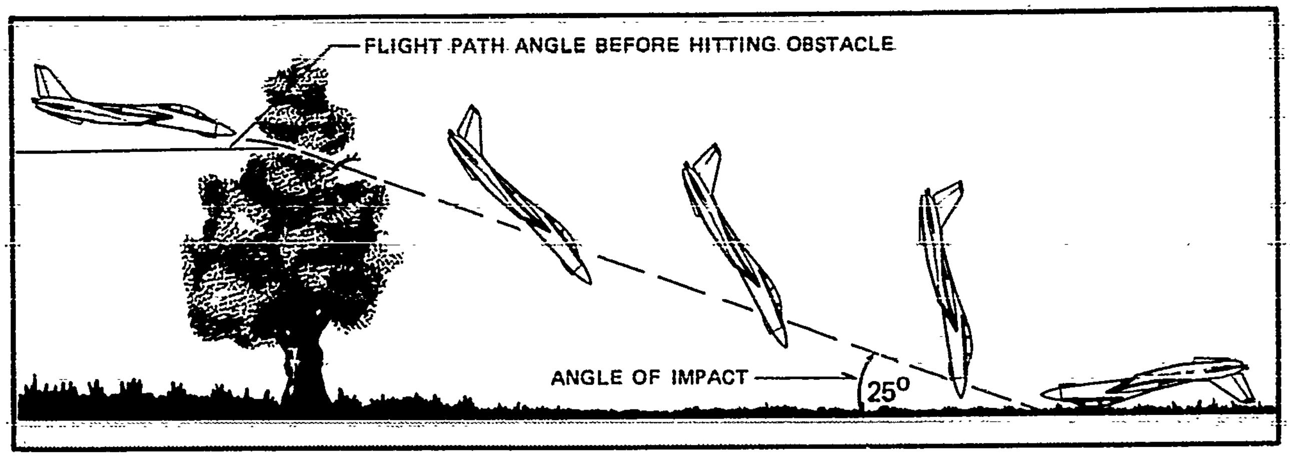


Figure B-4. Difference Between Flight Path Angle and Angle of Impact

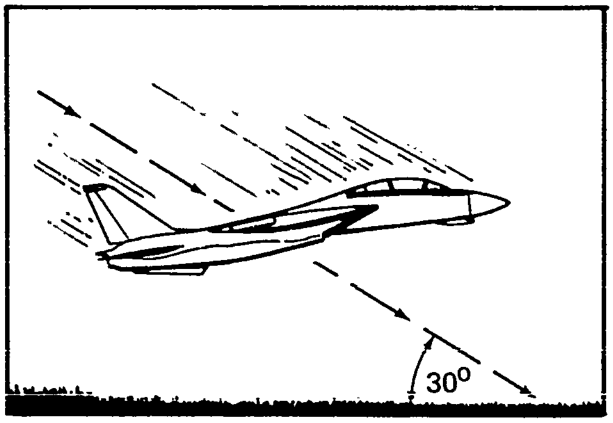


Figure B-5. 30-Degree Angle of Impact

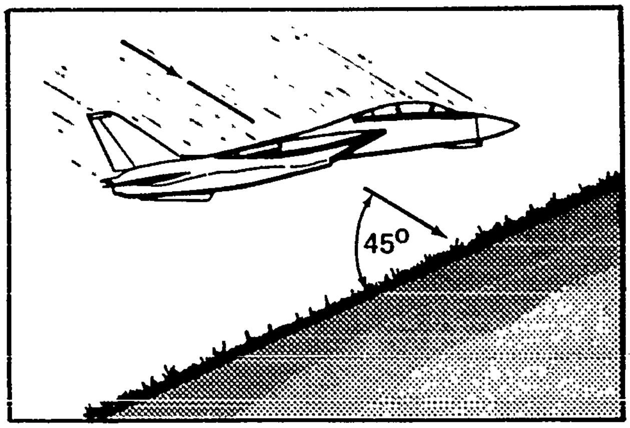


Figure B-7. 45-Degree Angle of Impact

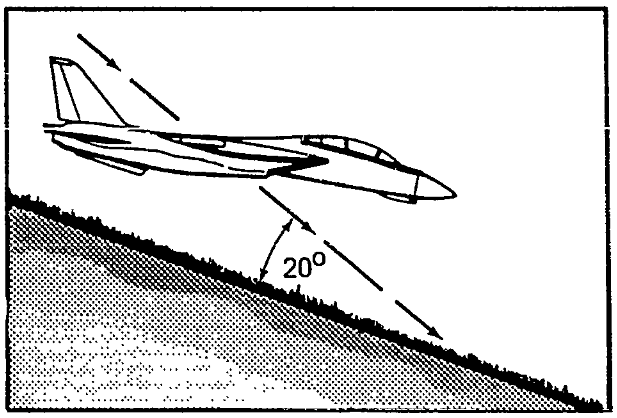


Figure B-6. 20-Degree Angle of Impact

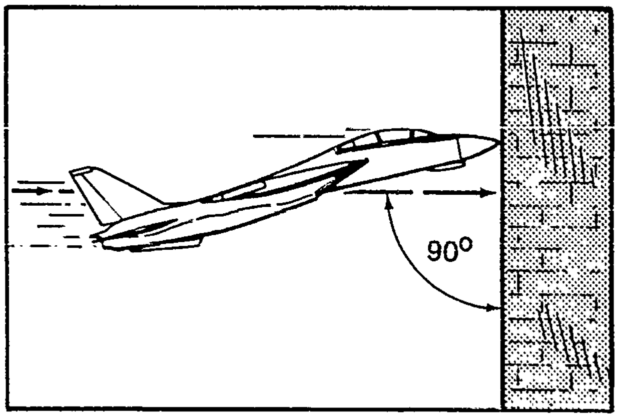


Figure B-8. 90-Degree Angle of Impact

B-7. SPEED OF AIRCRAFT PRIOR TO HITTING OBSTACLES.

B-8. It is generally possible to estimate the speed of the aircraft before hitting obstacles and at impact by questioning qualified witnesses and by considering the wind, the aircraft's maneuvers, and its characteristics–such as cruising, approach, and stalling speeds.

B-9. If the plane strikes wires, trees, or other obstacles at flying speed, a great deal of energy may be absorbed, slowing down the aircraft before impact with the ground. In such cases it is difficult to make more than an educated guess as to the final impact speed. Angle of impact, wreckage distribution, and size and shape of the ground scar are useful factors in estimating final impact speed. Many modern aircraft are equipped with Mach trim limiting devices which will indicate speed at impact. Variable geometry engine inlet ramps and guide nozzles, when their position is taken in context with other factors, may also give clues.

B-10. The effect of wind on impact speed can be estimated by the use of figure B-9.

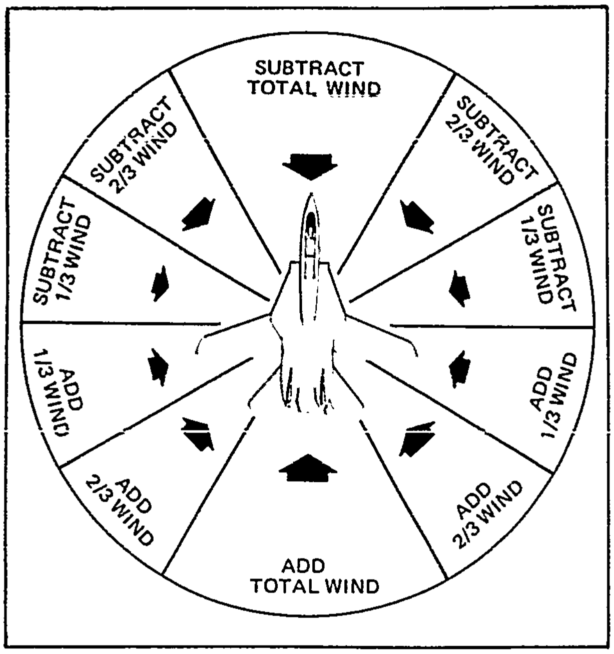


Figure B-9. Estimating Wind Effect on Impact Speed

B-11. ANALYSIS OF GROUND SCAR.

B-12. STOPPING DISTANCE OF AIRCRAFT. One of the important things to know about a crash is not how fast the aircraft was going, but how fast it stopped. The distance through which an aircraft's speed is stopped is most important. A crash is an absorption of kinetic energy. Crash energy is dissipated by 1) sliding, rolling, bouncing, or cartwheeling along the ground, 2) gouging into the ground, 3) deformation, buckling, or crushing of aircraft structures, and 4) crumpling or breaking of objects the aircraft strikes.

B-13. In low-angle accidents, aircraft frequently slide, bound, or cartwheel for 100 feet or more. On the other hand, in a very high-angle accident (steep nose-down angle), an aircraft may not move from the principal point of impact, the nose of the aircraft burying itself in the ground. In such accidents, the speed is stopped and the energy is absorbed in the collapse of the structure and gounging into the ground. The stopping distance can usually be quite accurately measured.

B-14. LENGTH AND DEPTH OF GOUGE MARKS. The length and depth of gouge marks are items of extreme importance, especially in high-angle accidents, for they provide valuable information which is used, along with other data, to estimate the crash forces transmitted to the fuselage structure, seats, safety belts, and shoulder harnesses of the occupants. In measuring the length and depth of gouges, do not include the distance the aircraft bounced, slid, or cartwheeled, since an aircraft stops much more abruptly when gouging in than it does when sliding. For example, in figure B-10 the total distance from the point where the aircraft first struck the ground to the point where it came to rest is 102 feet. Only 32 feet of this was gouging. In figure B-11 the aircraft gouged in, bounced, gouged in again, and then slid. When two separate gouges occur, as in this case, the length of both gouge marks should be added together. Although the aircraft bounced 26 feet and slid 42 feet, the total gouging distance was only 7 feet with a maximum depth of 5 inches.

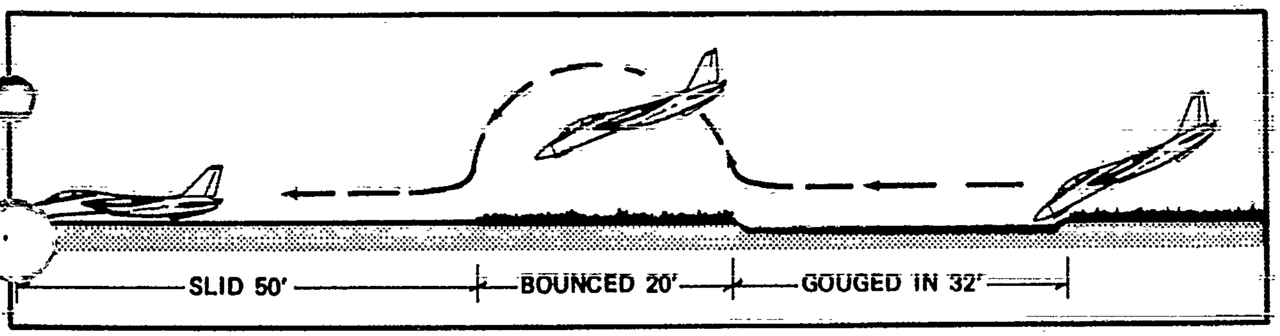


Figure B-10. Length and Depth of Gouge Marks Should be Measured Accurately

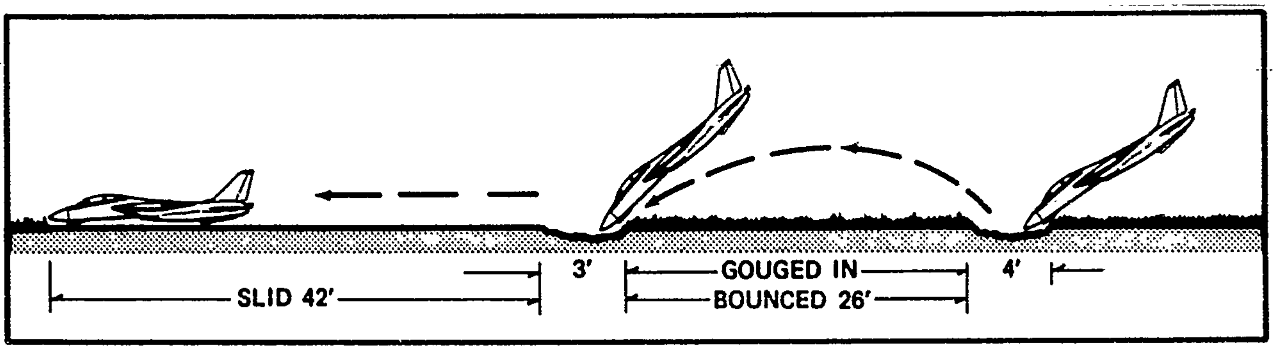


Figure B-11. Length of Individual Gouge Marks Should be Added Together.

APPENDIX C.

PHOTOGRAPHS

C-1. PHOTOGRAPHIC RECORD.

C-2. In almost every accident, a certain minimum number of photographs is usually required for record purposes if the investigation report is be complete. Photographs in this category are used chiefly for verification and identification purposes. In accidents involving structural failure or suspected structural failure, however, a more or less complete photographic record is usually made to assist in subsequent investigation and evaluation work.

C-3. A complete photographic record should include photographs of the general terrain at the site of the accident, overall views of undisturbed wreckage, reconstructed components or systems and close-up views of important or significant structural or other material failures. The terrain pictures should show any surface irregularities, presence of damage to buildings, trees, or other objects, point of first contact, impact craters, etc. The photographs should be taken as soon after the investigator arrives at the scene as possible, since subsequent investigation work or other conditions may alter or destroy the evidence. After the terrain pictures have been obtained, the investigator should concentrate on photographing the undisturbed wreckage. The emphasis here should be on showing the attitude of the aircraft when it struck the ground, the general extent of damage and the presence or absence of all major components such as the wings, stabilizers, elevators, rudder, ailerons, etc. If fire indications are found in various areas of the wreckage an effort should be made to show these indications, together with similar indications, possibly, on the surrounding ground. These latter photographs can be used often to substantiate findings of ground fire versus inflight fire. Other points which appear to be significant from a preliminary examination should be recorded before the detailed wreckage examination is begun. Very often the investigator will decide to reconstruct or rearrange particular parts of the wreckage to determine failure patterns. A photographic record should be made of such reconstruction work to assist in the subsequent evaluation work. Finally, close-up views of important structural failures such as failures of spar caps, webs, spar splices, longerons, or stringers, should be included in the photographic record.

C-4. In general, the photographic record should be complete enough to permit a person who is reviewing and evaluating the accident report to appreciate the significance of the investigator's finding. While the investigator's report must contain a detailed write-up of the damage, it is still true that one picture can often take the place of a great number of words. The investigator should use photographs as another tool in complete and accurate reporting. Each photograph included in the report should purport to show a separate point or detail relative to the accident.

C-5. The sooner an experienced and qualified photographer can get to the scene of an accident the better are the possibilities of acquiring more valuable photographic evidence. The photographer should commence taking pictures immediately upon arrival. Pictures taken before extensive fire damage can reveal information that would ordinarily be lost.

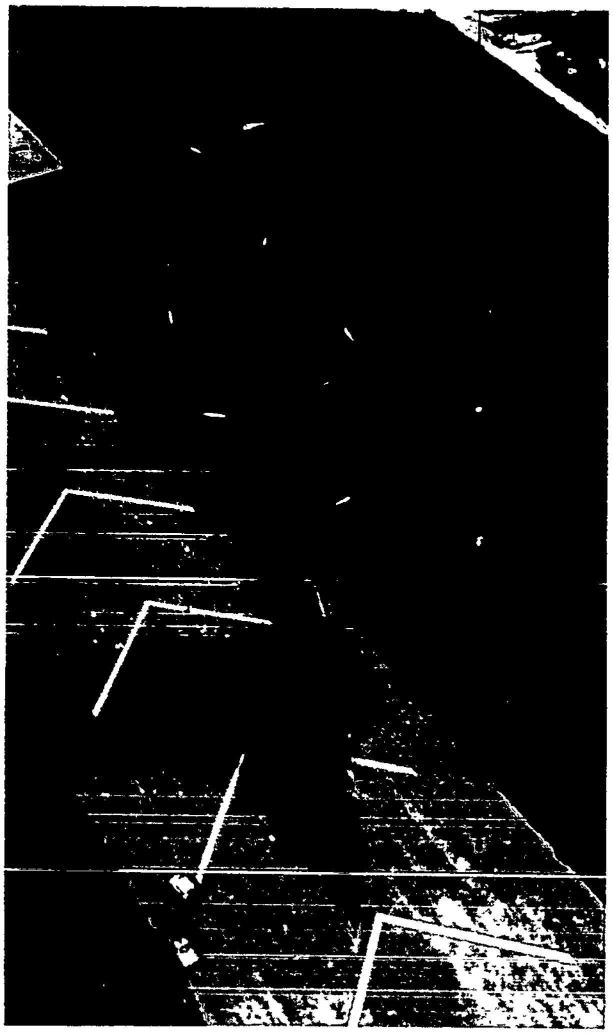


Figure C-1. Photographic Record Should Include View Along Wreckage Path

C-6. If evidence is to be presented, get a good picture of it. The photographer is not a mind reader and he cannot be expected to get pictures contained in the investigator's mind. It will normally be necessary to show the photographer exactly what is to be photographed and from what angle and direction. Take as many pictures as necessary but do not photograph indiscriminately and end up with a voluminous stack of exposed plates and no concrete evidence. Use of polaroid-type cameras is advantageous since the investigator can determine at the scene whether the required photographs have been taken and all important details of the wreckage have been documented.

C-7. Starting as early in the game as possible, and as the investigation progresses, the accident board should review photographic proofs for those shots which are to be later printed for the record. Identification is very important during this process. Also, judicious cropping will enhance the photographic record by eliminating extraneous peripheral items and will allow the photographer to enlarge the items of pertinence. Crop marks can be made directly on the proofs with grease pencil.

C-8. Pertinent photographs of the following details are desirable:

1. General view of the scene along the wreckage pattern to the point of first contact.

2. Aerial view of the accident scene (if needed).

3. Damage to objects struck.

4. All major parts of the wreckage.

5. Detailed view of cockpit, instrument panels, switch settings, and control handles.

6. Engines and propellers.

7. Wheels and landing gear assemblies.

8. All parts involved in, or suspected of structural failure, or of having contributed directly to the accident. These photographs should be in

sufficient detail to show the grain of the metal at the failure point, or other detailed information such as direction of shear of rivets, etc.

9. The failed part that has been established as the cause of the accident or is believed to be significant to the cause of the accident should be photographed in detail. It is good practice to photograph the failed part and an undamaged like item in the same exposure so that the failure is readily apparent.

C-9. Regarding the photographing of small, important pieces of evidence, the parts should not only be photographed in the field but they should be removed from the scene and photographed in a laboratory under controlled conditions to insure that the photograph of the items in question will be clear and well defined.

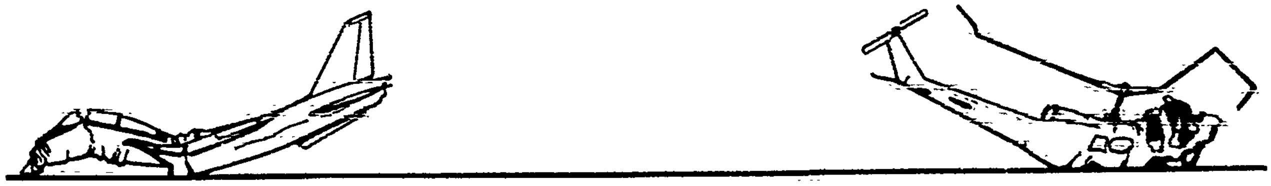
C-10. IDENTIFICATION OF PHOTOGRAPHS.

C-11. In order to avoid confusion, all photographs should be given exhibit numbers and should carry descriptive captions to point out the details of evidence to which they contribute. A good method of accomplishing this is to write the captions on a piece of plain white paper with grease pencil, placing this sign in the foreground of the picture. A picture without an explanation is as confusing as it is worthless.

C-12. The location of the photographer and the direction in which the photographs were taken must be recorded carefully. In order to secure better coverage, it is often necessary to rephotograph scenes or specific items of evidence from more than one direction.

C-13. Each photograph should be readily identifiable and to insure this necessary requirement it may be necessary to request that all photographs be identified with the following information:

1. Date of accident.
2. Location of accident.
3. Type of accident.
4. BuNo of aircraft.
5. Part number (where applicable).
6. Squadron.
7. Aircraft accident report number.
8. Special handling note.



APPENDIX D.

DIAGRAMS, SKETCHES, AND MAPS

D-1. WRECKAGE DISTRIBUTION DIAGRAMS.

D-2. The location of the wreckage on the ground often reveals interesting and pertinent facts in an investigation. A diagram of the wreckage location should be plotted as soon as possible after an accident to preclude the possibility of some pieces being moved before their exact position is noted.

D-3. It is usually wise for the investigator to take very detailed notes as he makes a complete inventory of the aircraft parts and records their relative location. A general sketch of the accident locale is highly desirable in most accidents but particularly in the more serious ones. Sometimes it is very difficult to plot because of dense undergrowth, hilly terrain, swampy land, etc. However, in almost every case properly prepared sketches and diagrams showing wreckage distribution and the general setting of the accident are invaluable, and every effort should be made to prepare them regardless of the difficulty.

D-4. To avoid overcrowding of information, it may be necessary to prepare several diagrams, showing different data on each one. Together these sketches should allow the reviewers of the accident report to grasp quickly the circumstances and location of the accident. The general setting of the accident should be shown by giving the bearing and distance of all equipment and pieces of structure from the center of the wreckage or from some stationary reference point.

D-5. Rough diagrams and sketches drawn early in the investigation usually prove invaluable when more exact and elaborate diagrams are prepared for the final report, using the investigator's notes and witnesses' statements.

D-6. Information that should always be shown on the wreckage distribution diagram includes the following: (See figure D-1.)

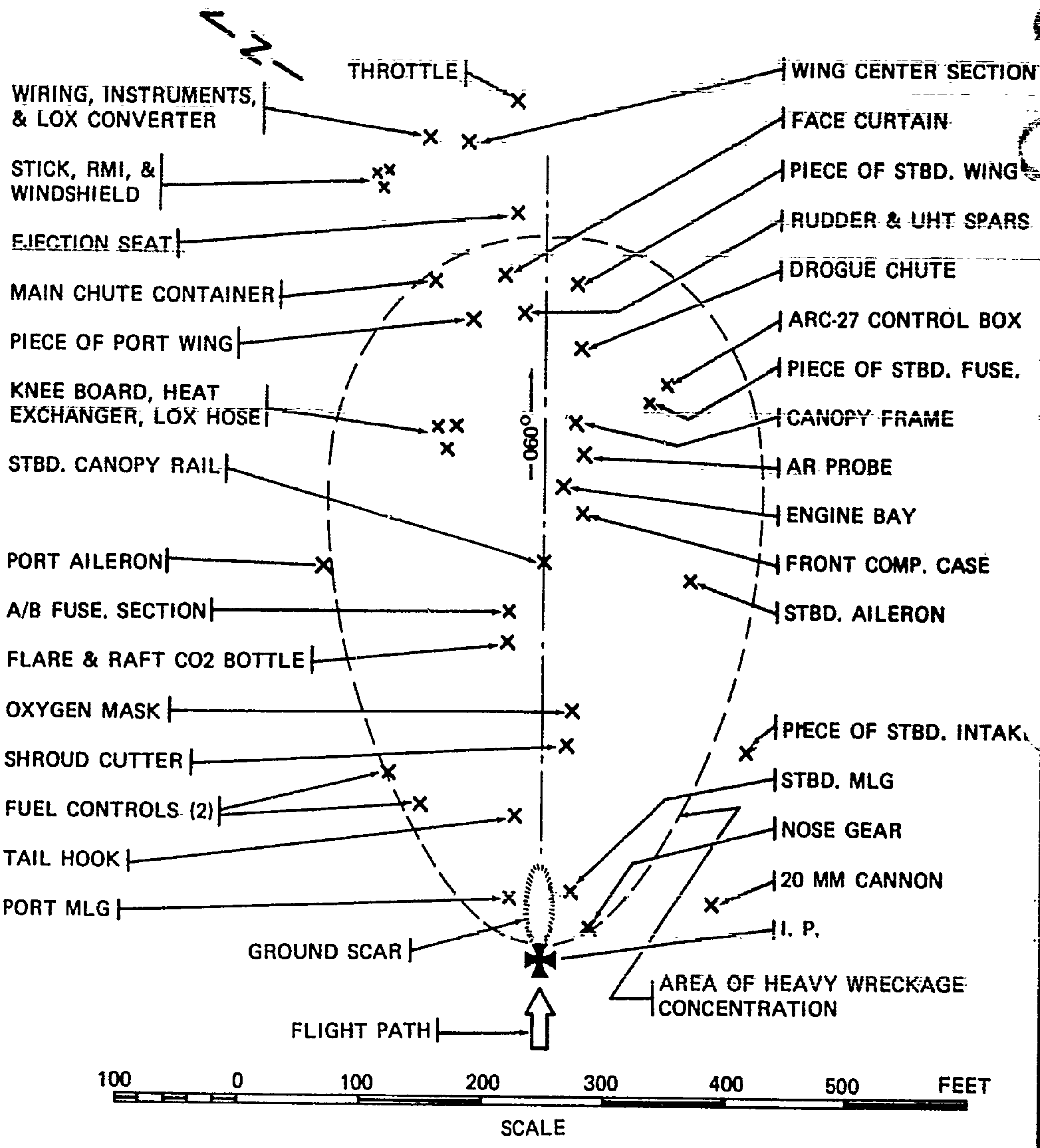
1. Bearing and distance of all significant pieces of wreckage from a stationary reference point.

2. Point of initial contact.

3. Location of deceased or injured people.

4. Propeller or other marks on the ground.

5. Landmarks or features of terrain such as hills, fences, roads, trees, buildings, etc., if they figure in the accident.



Notes:
1. I.P. Longitude 94 deg 41.8' West, Latitude 45 deg 18.8' North
2. Elevation: 202 ft.
3. Landmark: 320 deg/1200 ft to flag on beach
4. Aircraft Data: 40 to 45 deg impact angle; 5 to 10 deg nose up; 300 KIAS
5. Ground scar: 70 ft long, 10 ft wide & 3 ft deep
6. Weather at time of accident: 0&5 6 60/54 LGF 027

Figure D-1. Wreckage Distribution Diagram

D-7. OTHER DIAGRAMS.

D-8. In addition to the wreckage distribution diagrams, other sketches and maps may prove useful in the investigation. The flight-path of the aircraft prior to impact should be reconstructed in a diagram based on witnesses' testimony and its track along the ground should be presented, using the investigator's measurements (see figure D-2). If the aircraft was in trouble for a considerable time before its crash, then its course during this period should be detailed on a route map. Sketches should also show, where appropriate:

1. Distance and direction to nearest airport, town, or airway aid.

2. Elevations (mean sea level) at scene of accident.

3. Compass rose or north point and wind direction.

4. Path of aircraft.

5. Distances between important points or objects.

6. Naval Air Station obstructions; runway and glide-path maps.

7. Naval district maps.

D-9. There have been many instances when

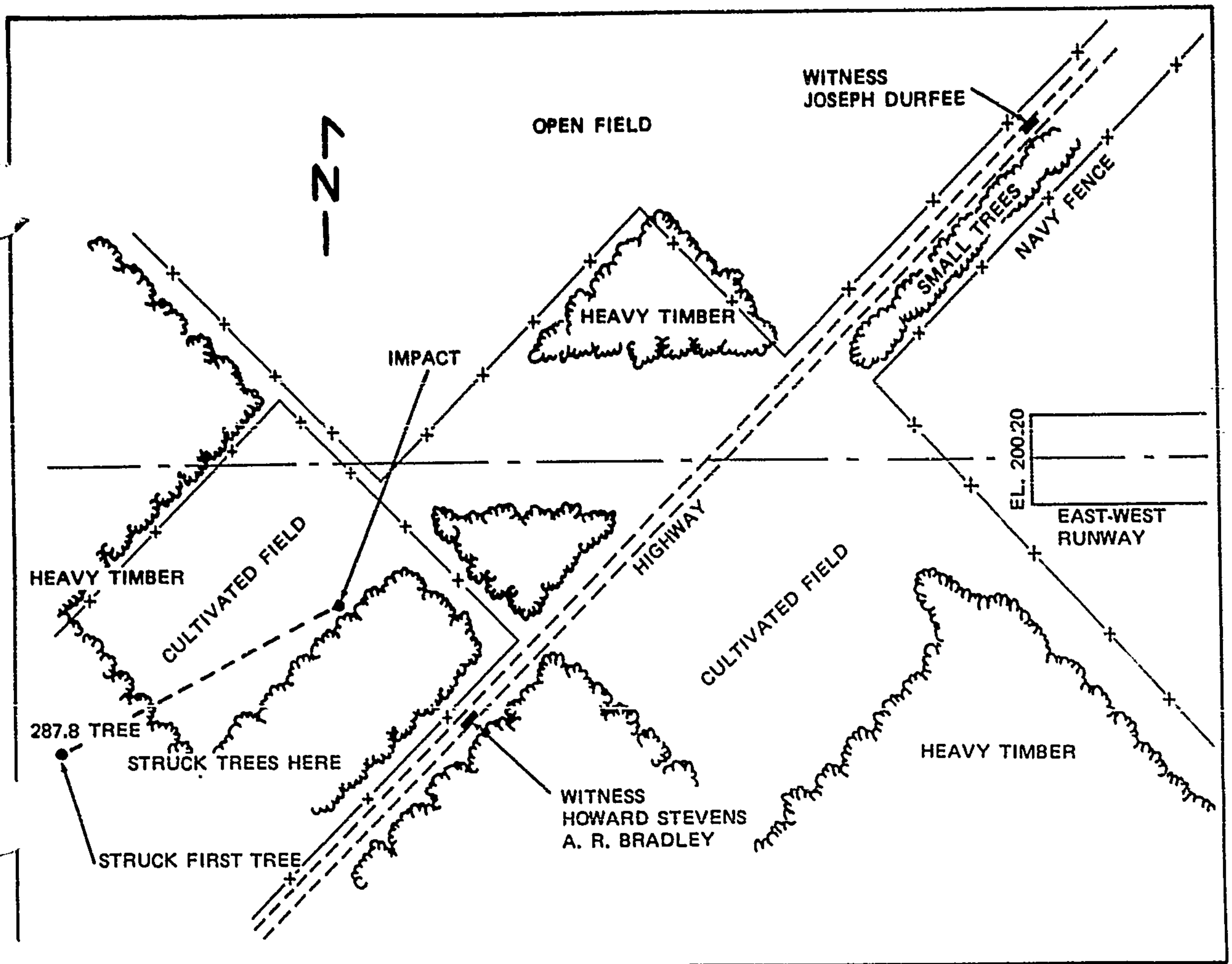


Figure D-2. Flight Path Diagram

sketches have provided the best and most usable data regarding a particular phase or the results of an aircraft accident. Sketches are of particular value when disintegration occurs in flight and the components are apt to be scattered widely along the flight-path. Other sketches of the particular aircraft involved, showing the location of missing parts by cross-hatching, are often used with considerable success.

D-10. Sketches may also be used to show details of taxiing accidents, collisions, proximity of obstructions to runways or taxiways, width or condition of runway, size and layout of emergency landing sites, and similar special conditions involved in accidents.

D-11. Other sketches showing details of structural failures, position of controls or control surfaces, flaps, or landing gear, etc., may suggest themselves or may be used in lieu of photographs to record important details of the accident. All sketches should be clearly identified, showing the time, place, and date of the accident, the name of the operator, and type and Bureau number of the aircraft involved. It is also important that sketches carry an exhibit number and a title indicating their contribution to the accident record.

D-12. MAPS AND CHARTS.

D-13. For the purpose of locating the scene of thecrash, a sectional aeronautical chart is useful. This will give detailed information on the crash scene's location with reference to airways, navigational facilities, and major terrain features. There are numerous other sources of special maps which can be used when unusual topographical conditions are a factor in causing the accident. Some of them are:

1. Hydrographic Office.

2. U. S. Forest Service.

3. State and county agricultural service agencies.

4. Army Map Service (extremely detailed maps are available from this source).

5. State, county, and city surveyor's offices.

6. Naval Air Station obstruction, runway, and GCA glide-path maps.

7. Naval district maps.

D-14. MEASURING DISTANCES.

D-15. Pacing is usually sufficient for distance measurements where wreckage is scattered over a large area. If the area is heavy with brush or trees, triangulation may be necessary. A pair of field glasses with a mil scale can also be used for larger distances across impassable terrain. Exact distances are usually required for wheel skid marks, length and depth of initial impact marks when the aircraft hit at a shallow angle, propeller ground scars, position of controls, position of components, etc. A steel measuring tape should be used for this purpose.

APPENDIX E.

QUESTIONS FOR AIRCRAFT ACCIDENT INVESTIGATORS

E-1. INTRODUCTION.

E-2. The list of questions in this appendix is meant to serve only as a guide to the investigator in reviewing his evidence for completeness. It is not meant for use in interviewing witnesses or in gathering evidence. Many of the questions will not be applicable to a given aircraft accident, and there will always be some facet of the accident not covered by this appendix. The investigator who limits his efforts to answering the questions listed here will acquire much superfluous information, and will invariably fail to determine the cause of the accident.

E-3. OPERATIONAL PROCEDURES.

E-4. PREFLIGHT PLANNING, TAXIING, AND PRE-TAKEOFF.

1. Was the flight properly authorized and what type of mission?

2. Was preflight navigational and/or route planning completed properly?

3. Was flight clearance DD Form 175 or local flight plan completed?

4. Who was clearance authority and was he qualified to sign for the clearance?

5. Was pilot's instrument rating valid?

6. Was Form F (weight and balance) properly filed?

7. Was the deicing equipment serviced?

8. Was a fuel sample taken?

9. Was there sufficient fuel on board to accomplish the mission as proposed and remain within existing regulations with respect to fuel reserve?

10. Was the pilot in possession of a flashlight, maps, letdown procedures, radio data, and flight information manuals?

11. Was OPNAV Form (yellow sheet) properly executed, and was plane listed as being in an "up" status?

12. Did pilot accept the plane with known discrepancies?

13. Were crew and passengers properly briefed?

14. Was proper visual inspection made?

15. Were chocks placed under the wheels prior to starting the engine?

16. Was any difficulty encountered in starting engine?

17. Was a checklist used?

18. Prior to taxiing, were tower instructions received and understood?

19. Were tower instructions adequate?

20. Were windshield and canopy clear?

21. Was proper taxi clearance available? If not, were wing walkers or guides available?

22. Were brakes operating satisfactorily before taxiing?

23. Were bomb bay doors and access doors closed and extensible units stowed?

24. Were all obstructions properly marked or lighted?

25. Was taxiing accomplished within existing regulations?

26. Were all flight and engine instruments checked during taxiing?

27. Were any peculiarities noted while taxiing?

28. Was line or deck crew properly equipped for night operations, and for emergencies?

29. Was line or deck crew familiar with current signals?

30. Were proper position lights on prior to taxiing?

31. Were landing lights used properly while taxiing?

32. Was tower checked for light signals? Were the signals understood?

33. Was the pilot guilty of taxiing with his head in the cockpit?

34. Was the adjustment of belts, chutes, harness, and equipment made prior to taxiing?

35. Was steering mechanism or tailwheel lock operating satisfactorily?

36. Was area behind aircraft cleared prior to power check?

37. Was nosewheel or tailwheel in proper position?

38. What was the position of flaps prior to takeoff?

39. Was checklist used for engine run-up?

40. Were brakes checked against power prior to getting head in the cockpit for engine run-up?

41. Were any discrepancies noted on run-up?

42. Was all necessary radio equipment checked and operating properly?

43. What type of radio equipment was available?

44. Were takeoff instructions including ATC instructions received prior to takeoff?

45. Were gyro instruments uncaged or checked for proper operation prior to takeoff?

46. Were control locks, external gear-down locks, and bomb bay door safety locks removed?

E-5. TAKEOFFS.

1. Was full power used for takeoff?

2. Was safe speed attained prior to leaving ground?

3. What sequence was employed in retracting gear, flaps, reducing power?

4. Was partial or complete loss of power experienced? If so, what action was taken?

5. Did props or engine overspeed on takeoff?

6. Were flaps or gear prematurely retracted?

7. Was proper signal given by the pilot for retraction of gear and flaps?

8. Was safe single-engine speed attained prior to the first power reduction?

9. Was safe altitude attained prior to making first turn?

10. Was a turn made without visually clearing area?

11. Were brakes applied after becoming airborne and prior to retracting gear?

12. Were landing lights used for takeoff? When were they retracted or turned off?

13. What was direction and velocity of wind in relation to takeoff?

14. Was loss of directional control experienced as a result of brake seizure, blowout, loss of power, or misuse of controls?

E-6. IN FLIGHT.

1. What was the attitude of the aircraft prior to impact?

2. Did the aircraft crash in a dive, spin (steep or shallow), inverted, or unusual position?

3. Did fire or explosion occur prior to crash?

4. Was radio failure a factor?

5. Was airspeed reduced when encountering extreme turbulence?

6. Were standard or approved procedures used in letting down?

7. Was cruise control employed properly?

8. Was there a willful violation of flying regulations? Were proper maneuvers being practiced?

9. Did a stall or spin occur?

10. Were one or more props feathered?

11. Did pilot feather needlessly?

12. Were external fuel tanks and canopy jettisoned prior to impact?

13. Was aircraft part of a formation?

14. Was proper air discipline observed?

15. Were proper position reports made?

16. Were ATC or ADIZ instructions, if any, adhered to?

17. Was flight plan followed?

18. Was adequate supervision exercised by the instructor pilot?

19. Was clearance properly executed?

20. Was the aircraft operated within the limits of the VN, VG diagram?

E-7. LANDING.

1. Was a waveoff attempted?

2. At what altitude was decision made to go around? What airspeed?

3. Was slipstream encountered?

4. Was unnecessary drag caused by leaving flaps down too long, or extending flaps too soon?

5. Was letdown clearance obtained and complied with?

6. Were both pilots concentrating on instruments during instrument letdown or was one pilot looking for the ground?

7. Was GCA used? If

8. Was ILS being used? If "Yes", comment.

9. Was APCS or other approach aid used?

10. Were proper landing instructions received and complied with?

11. Were gear or flaps lowered at excessive speed?

12. Was trouble encountered lowering gear or flaps?

13. What degree of flaps was used?

14. Were all warning devices functioning properly?

15. Where was point of touchdown on runway?

16. Was landing hard?

17. Were there skid marks on ground? What did they indicate?

18. Did aircraft bounce? If so, what corrective action was taken?

19. Were excessive brakes used? Were emergency brakes used?

E-8. WEATHER

1. Was vision impaired for any reason?

2. Was weather encountered as forecast? If not, what was the weather encountered?

3. What was visibility on the ground? At flight altitude?

4. Was a listening watch kept on weather broadcast in flight?

5. Was deicing system installed and functioning properly?

6. Did weather, current and forecast, meet existing minimums?

7. Was flight VFR or IFR, day or night?

E-9. **MATERIAL PROCEDURES.**

E-10. AIRFRAME.

1. Did structural failure appear to have preceded impact? What was the sequence of failure?

2. Were any control surfaces or structural parts found at a distance from the main wreckage? If so, how far? Make a diagram of all parts in relation to the point of impact.

3. Did seats break loose on impact? Was evidence of structural failure adequately photographed and described? (Preserve for detailed study if failure indicates design defect.)

4. Was there evidence of fire in flight?

E-11. FLIGHT CONTROL SYSTEM.

1. What was the condition of controls, control cables, linkages, boost, and power control equipment?

2. Was there any evidence of contamination in the power control system filter elements or pumps?

3. Was there any evidence of loss of control system fluid or pressure?

4. What were trim tab and/or trim tab actuator settings?

5. Was automatic flight control system engaged?

6. Were there any obstructions to free movement of the controls?

E-12. LANDING GEAR.

1. Was there a failure of landing gear or actuating cylinder?

2. Was the landing gear warning device functioning properly?

3. Were main gear UP and DOWN locks in place?

4. Was the nose wheel shimmy damper in position? Was there sufficient fluid?

5. If emergency extension was required, was correct procedure used? Did system function properly?

6. Were wheels properly installed and bearings lubricated?

7. What was the position of the cockpit control?

E-13. TIRES AND BRAKES.

1. Was there a failure of tire or brake assembly?

2. Were the tires recaps?

3. Were the treads greater than the specified thickness?

4. Were tires and tubes of the correct size?

5. Were proper pressures being utilized?

6. Did brakes lock, overheat, or catch fire?

E-14. INSTRUMENTS.

1. When were the flight instruments last checked?

2. Was the pitot cover removed?

3. Was pitot heat used?

4. Were the instruments properly marked for maximum, minimum, and normal operations?

5. What was the altimeter setting on the pressure altimeter?

6. Was radar altimeter in use? Set on which scale?

E-15. POWERPLANTS.

E-16. Gas Turbine Engines.

1. What was the position of cockpit engine controls? What were the positions of engine controls at the engine?

2. Were fuel samples free of contamination?

3. Was there any evidence of damage caused by foreign objects?

4. Was there any evidence of compressor or turbine blade failure? Compressor stall? Compressor or turbine shaft failure?

5. Was the engine developing power upon impact?

6. Was there any evidence of failure of accessory drives, accessories, or accessory mounts?

7. Was there any evidence of failure of reduction gear or torque sensing systems (turboprops and turboshafts)?

8. Was there any evidence of engine overtemperature?

9. Was there any evidence of lubrication

failure? What was the condition of lube oil strainers, pumps, and lube oil samples?

10. Was there any malfunction of the afterburner or afterburner controls?

11. Was there any evidence of malfunction of the fuel control?

12. If flameout occurred, was fuel mismanaged or exhausted?

13. Was a safety engineering investigation requested on the engine or components?

14. What were positions of variable angle inlet guide vanes and stator blades, and variable exhaust nozzles? Were positions consistent with other control settings?

E-17. Reciprocating Engines.

1. Was there any evidence of material failure in engine, such as swallowed valves, cracked cylinders, loose or damaged exhaust stacks, or failures in accessory drives or accessories?

2. What was the condition of the supercharger?

3. What was the condition of fuel from traps, strainers, and carburetor?

4. Was lubrication system functioning normally? Pump, lines, regulator, quantity? What did lube oil samples indicate?

5. What were blade angles of propellers and prop governor settings?

6. What were positions of operating controls of engine (mixture, rpm, throttles, etc.)?

7. Was there any evidence of engine fire?

8. Were throttle, supercharger, and prop control levers and linkage in proper conditions?

9. Were carburetor heat doors and controls in the proper position?

10. Were oil-cooler shutters, air-scooop, and cowl flaps in proper position?

11. What was the condition of the spark plugs? Did they check out? New or overhauled? Were they an approved model in accordance with current General Engine Bulletins?

12. Did other parts of the ignition system check out?

13. Was safety engineering investigation requested?

E-18. FUEL SYSTEM.

1. Was the quality and type of fuel being used suitable, and was fuel obtained for analysis?

2. Was foreign matter contained in the fuel strainer?

3. Was a break or leak found in fuel lines?

4. Was the fuel supply exhausted?

5. Were fuel selector valves and mixture controls in the proper position?

6. Were gas fumes detected at any time? What action was taken?

7. Was the jet fuel regulator or carburetor given a functional check?

E-19. HYDRAULIC SYSTEM.

1. Was there any evidence of contamination in the hydraulic filters or pumps?

2. Was there any evidence of loss of fluid or pressure from any of the hydraulic systems?

3. What was the condition of hydraulic pumps and hydraulic lines?

4. What were the positions of all hydraulic actuators and cockpit controls? Did they

correspond?

5. Was the quantity and type of hydraulic fluid correct?

6. If one or more hydraulic systems failed, was power still available to operate primary flight controls?

E-20. ELECTRICAL SYSTEM.

1. Were generator, inverter, and booster switches on?

2. Was generator producing proper output?

3. Was ram air turbine or other auxiliary power source deployed?

4. Was there evidence of open or short circuits, or arcing in the aircraft wiring?

5. Did fire warning circuits function?

6. Were circuits operating flight controls functioning properly?

7. Was the cockpit lighting adequate?

8. Were navigation and formation lights operative?

E-21. PERSONAL SAFETY EQUIPMENT.

1. Were shoulder harness and safety belts fastened at the time of impact?

2. Were emergency exits used? Did they function properly?

3. Were parachutes used? How many were used successfully?

4. When were parachutes last inspected?

5. Were engine or cabin fire extinguishers used or incorrectly used?

6. Were safety belts available for all crew members and passengers?

7. Was necessary emergency equipment, such as Mae West and parachutes available for type of mission to be performed?

8. Was oxygen mask in use, recently cleaned and tested, and functioning properly?

9. Was oxygen supply adequate? Amount remaining?

10. Were converters functioning properly?

11. What was regulator setting? Date last checked?

12. Was emergency oxygen (bailout bottle) used and/or functioning properly?

13. Was ejection attempted by pilot and crew member(s). Did seats function properly? If not, was emergency harness release handle pulled?

14. When was seat last overhauled? When were charges checked?

15. Were face curtain locks disengaged and all safety pins removed from ejection seats?

16. If ejection was successful, did time release mechanism, barostat and "G" - controller, and parachutes function properly?

E-22. MISCELLANEOUS.

1. To what frequencies were radios tuned?

2. Was the proper crew member familiar with the radio equipment he was expected to use?

3. Were armament switches in the proper position if bomb bay or external tanks were being used?

4. Was the visual inflight check made of ordinance in use?

5. Were all safety pins removed from

armament, drop tanks, pylons, etc.?

E-23. HELICOPTERS.

1. Was ground resonance encountered?

2. Did loss of airspeed occur at low altitude?

3. Did inadvertent loss of rotor rpm occur?

4. Was center of gravity within specified limits?

5. In cases of engine failure, was altitude sufficient for an autorotation?

6. Was collective pitch reduced quickly after engine failure?

7. Did main rotor blades fold or fail?

8. Did tail rotor fail?

9. Did main rotor control linkage fail?

10. Was fuselage swinging or rotating because of torque?

11. Did drift tip the fuselage and allow the main rotor blade to touch the ground?

12. Did main rotor blade stall occur?

13. Did main rotor blades strike ground?

14. Did tail rotor strike any object?

15. Did material failure occur in engine, transmission(s), main drive, tail rotor, or control system?

16. ~~Was ASE functioning properly?~~

17. Were fluid and air pressures in struts correct?

18. Was tire pressure correct?

E-24. MISSING AIRCRAFT/CREW MEMBERS.

1. Was flight plan properly filed and crew briefed on mission?

2. Were all radio contacts traced?

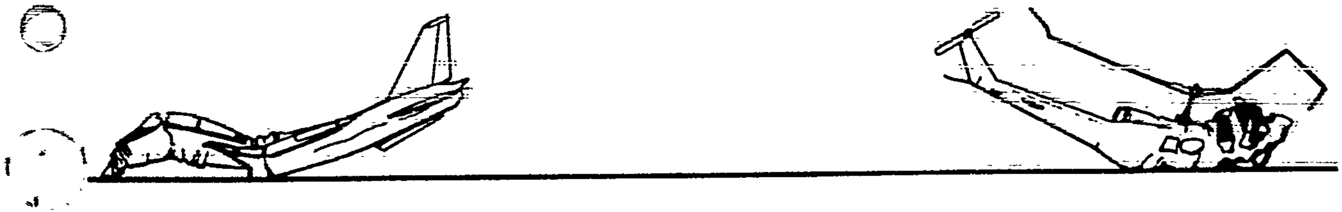
3. Was sufficient fuel available, considering existing winds on route forecast?

4. What was existing weather over proposed route?

5. Were all areas within range of missing aircraft searched according to procedures in current Search and Rescue Manual?

6. Were crew members properly trained in bailout/ejection, ditching, and survival procedures?

7. Were aircraft emergency beacons and survival equipment in working order?



APPENDIX F.

MATHEMATICS FOR INVESTIGATION

F-1. INTRODUCTION

F-2. Finding the cause of many aircraft accidents requires a certain mathematical analysis. The purpose of this appendix is to provide a compilation of basic information which will be readily available to the aircraft accident investigator. The appendix is subdivided as follows:

1. Conversion factors . . Paragraph F-3
2. Natural trigonometric functions . . . . . Paragraph F-6
3. Aerodynamics . . Paragraph F-8
4. Performance . . . . Paragraph F-17

F-3. CONVERSION FACTORS.

F-4. Table F-1 lists common conversion factors which may be required during an aircraft accident investigation. Values in the table are based on the following conditions:

1. Columns of mercury are at 32°F and standard sea-level gravity.

2. Columns of water are at 59°F and standard sea-level gravity.

F-5. There are a few equivalents and approximations that, if remembered by the aircraft accident investigator, will prove to be a valuable aid in solving many problems involving speed and distance. Some of the most common and useful of these are shown as follows:

1. 1 mph = 1.467 ft/sec = 88 ft/min

2. 60 mph = 88.0 ft/sec = 5,280 ft/min

3. 100 mph = 146.7 ft/sec = 8,800 ft/min

4. 1 knot = 1.689 ft/sec = 101 ft/min = 1.1516 mph

5. 60 knots = 101.3 ft/sec = 6,080 ft/min

6. 100 knots = 168.9 ft/sec = 10,000 ft/min

F-6. NATURAL TRIGONOMETRIC FUNCTIONS.

F-7. Table F-2 contains natural trigonometric functions to be used in aerodynamic, performance, navigation, and triangulation calculations that may be required during the investigation.

Table F-1. Conversion Factors

MULTIPLY	BY	TO OBTAIN	MULTIPLY	BY	TO OBTAIN
Atmospheres	76.0	Cm mercury.	Horsepower (Cont)	.550	Foot-pounds/sec.
	29.921	Inches mercury.		76,040	Kilogm-meters/sec.
	33.899	Feet of water.		1.0139	Metric horsepower.
	10,332	Kilogm. per sq. m.	Inches of mercury at 0° C.	.03342	Atmosphere.
	14.696	Pounds per sq. in.			
	2,116.2	Pounds per sq. ft.		13.595	Inches of water.
	1.0133	Bara.		1.1329	Feet of water.
Cubic feet	28,317	Cu. centimeters.		.49116	Pounds per sq. in.
	1,728	Cubic inches.		70.727	Pounds per sq. ft.
	.02831	Cubic meters.		345.32	Kilogm. per sq. m.
	.08704	Cubic yards.	Inches of water	.07356	In. of mercury.
Cubic feet	7.4805	Gallons.		.18683	Cm. of mercury.
	28.316	Liters		.03613	Pounds per sq. in.
Degrees (arc)	.01745	Radians.		5.1981	Pounds per sq. ft.
Dynes	1.020×10^{-3}	Grams.		25.400	Kilogm. per sq. m.
	2.248×10^{-6}	Pounds.	Knots	1.0	Nautical miles/hr.
	7.233×10^{-5}	Poundals.		1.6889	Feet per second.
Feet of water	.02940	Atmospheres.		1.1516	Miles per hour.
	.43353	Pounds per sq. in.		1.8532	Kilometers per hr.
	62.378	Pounds per sq. foot.		.51479	Meters per sec.
	304.80	Kilgm. per sq. m.	Miles	5,280	Feet.
	.88367	Inches of mercury.		1.6093	Kilometers.
	.24199	Cm. of mercury.		.86839	Nautical miles.
Feet per minute	.01136	Miles per hour.	Miles per hour	1.4667	Feet per second.
	.01829	Kilometers per hr.		.44704	Meters per second.
	.40800	Cm. per second.		1.6093	Kilometers per hr.
Feet per second	.68182	Miles per hour.		.86839	Knots.
	1.0973	Kilometers per hr.	Miles/hr squared	2.1511	Feet/sec. squared
	30.480	Cm. per second.	Nautical miles	6080.2	Feet.
	.30480	Meters per second.	Pounds per sq. in.	2.0361	Inches of mercury.
	.59209	Knots.		2.3066	Feet of water.
Gallons, imperial	277.4	Cubic inches.		.06805	Atmospheres.
	1.201	U. S. gallons.		703.07	Kilogm. per sq. m.
	4.546	Liters.		.07031	Kilogm. per sq. cm.
Gallons, U.S. liquid	231	Cubic inches.	Radians	57.296	Degrees (arc).
			Radians per sec.	57.296	Degrees per sec.
	.13368	Cubic feet.		.15916	Revolutions per sec.
	3.7853	Liters.		9.8493	Revolutions per min.
	.83268	Imperial gallons.	Revolutions	6.2832	Radians.
	128	Liquid ounces.	Revs per min.	.10472	Radians per sec.
Horsepower	33,000	Foot-pounds/min.	Slugs	32.174	$\frac{\text{Pounds/sec}^2}{\text{ft.}}$

F-8. AERODYNAMICS.

F-9. EFFECT OF WEIGHT ON STALL SPEEDS. As a rule of thumb: a two-percent change in weight will cause a one-percent change in stall speed. As an example: an airplane at 10,000 lbs has a 1-G wings-level stall speed of 120 knots indicated airspeed. When operating at 11,000 lbs (a ten-percent increase in weight) the stall speed will be 120 + 6 = 126 knots (a five-percent increase).

F-10. EFFECTS OF BANK ANGLE ON STALL SPEED. Using table F-3 for reference, the stall

Table F-2. Natural Trigonometric Functions

ANGLE	SINE	COSINE	TANGENT	ANGLE	SINE	COSINE	TANGENT
0°	0.000	1.000	0.000	46°	.719	.695	1.036
1°	.018	1.000	.018	47°	.731	.682	1.072
2°	.035	0.999	.035	48°	.743	.669	1.111
3°	.052	.999	.052	49°	.755	.658	1.150
4°	.070	.998	.070	50°	.766	.643	1.192
5°	.087	.996	.088	51°	.777	.629	1.235
6°	.105	.995	.105	52°	.788	.616	1.280
7°	.122	.993	.123	53°	.799	.602	1.327
8°	.139	.990	.141	54°	.809	.588	1.376
9°	.156	.988	.158	55°	.819	.574	1.428
10°	.174	.985	.176	56°	.829	.559	1.483
11°	.191	.982	.194	57°	.839	.545	1.540
12°	.208	.978	.213	58°	.848	.530	1.600
13°	.225	.974	.231	59°	.857	.515	1.664
14°	.242	.966	.249	60°	.866	.500	1.732
15°	.259	.966	.268	61°	.875	.485	1.804
16°	.276	.961	.287	62°	.883	.470	1.881
17°	.292	.956	.306	63°	.891	.454	1.963
18°	.309	.951	.325	64°	.899	.438	2.050
19°	.326	.946	.344	65°	.906	.423	2.145
20°	.342	.940	.364	66°	.914	.407	2.246
21°	.358	.934	.384	67°	.921	.391	2.356
22°	.375	.927	.404	68°	.927	.375	2.475
23°	.391	.921	.425	69°	.934	.358	2.605
24°	.407	.914	.445	70°	.940	.342	2.747
25°	.423	.906	.466	71°	.946	.326	2.904
26°	.438	.899	.488	72°	.951	.309	3.078
27°	.454	.891	.510	73°	.956	.292	3.271
28°	.470	.883	.532	74°	.961	.276	3.487
29°	.485	.875	.554	75°	.966	.259	3.732
30°	.500	.866	.577	76°	.970	.242	4.011
31°	.515	.857	.601	77°	.974	.225	4.331
32°	.530	.848	.625	78°	.978	.208	4.705
33°	.545	.839	.649	79°	.982	.191	5.145
34°	.559	.829	.675	80°	.985	.174	5.671
35°	.574	.819	.700	81°	.988	.156	6.314
36°	.588	.809	.727	82°	.990	.139	7.115
37°	.602	.799	.754	83°	.993	.122	8.144
38°	.616	.788	.781	84°	.995	.105	9.514
39°	.629	.777	.810	85°	.996	.087	11.43
40°	.643	.766	.839	86°	.998	.070	14.30
41°	.656	.755	.869	87°	.999	.052	19.08
42°	.669	.743	.900	88°	.999	.035	28.64
43°	.682	.731	.933	89°	1.000	.018	57.29
44°	.695	.719	.966	90°	1.000	.000	------
45°	.707	.707	1.000				

Table F-3. Effect of Bank Angle on Stall Speed

ϕ BANK ANGLE	G's	STALL SPEED
0 degrees	1.00	100%
15 degrees	1.04	102%
30 degrees	1.15	107%
45 degrees	1.41	119%
60 degrees	2.00	141%
75 degrees	3.86	197%
80 degrees	5.76	240%

speed in a bank may be found once the wings-level 1-G stall speed in known.

1. Angle ϕ in figure F-1 is the bank angle in a steady turn. For these conditions the number of G's developed may be found by:

$$\text{G's} = \frac{1}{\cos \phi} = \sec \phi$$

2. Since the stall speed varies as the square root of the G's developed, a table may be made of G's and stall speeds versus bank angle (see table F-3).

F-11. RATE OF TURN AND RADIUS OF TURN. The rate of turn and radius of turn can be computed by the following formulas. The aircraft type has no direct effect as the main variables are airspeed and bank angle.

1. Radius of Turn. (See figure F-2.)

$$R = \frac{V^2}{11.26 (\tan \phi)}$$

Where: R = turn radius. ft

V = true air speed, kts

ϕ = bank angle

2. Rate of Turn.

a. $\text{R.O.T.} = 57.3 \frac{V}{R}$ (degrees/sec).

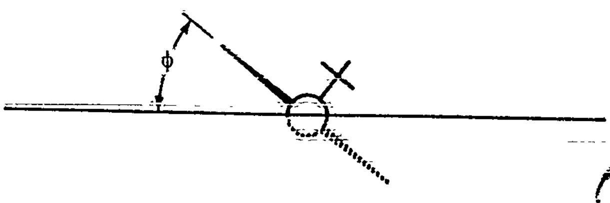


Figure F-1. Bank Angle

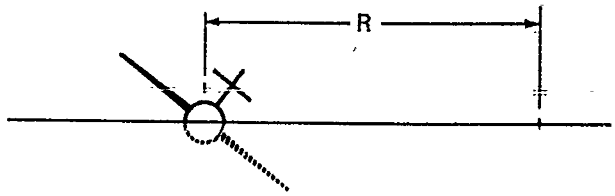


Figure F-2. Radius of Turn

b. Also, $\text{R.O.T.} = \frac{1091 (\tan \phi)}{V}$

F-12. ICE HAZARDS. Ice and frost always constitute hazards in the operation of aircraft. Of course, any icing which will cause a definite change in the contour of the airfoil surface will increase the adversity of the pressure gradient in that area and increase the possibility of separation of the airflow from the airfoil surface. Therefore, an aircraft encountering icing severe enough to cause separation will experience a definite increase in drag and stalling speed. A further hazard lies in the formation of ice on fuselage structures which may slough off into engine intakes. This "soft" FOD has been responsible for a number of mishaps.

F-13. The usual comparison between rime and clear ice, as shown in figure F-3, is usually to the effect that both types of icing result in a loss of airfoil effectiveness but that clear ice is definitely worse since it forms a large mushroom shape at the leading edge. Of course, this is true, but the impression most frequently conveyed is that only ice formations which result in a definite change

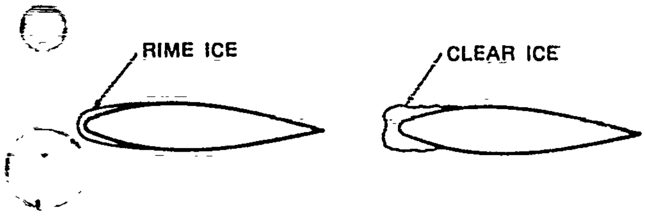


Figure F-3. Ice Formation

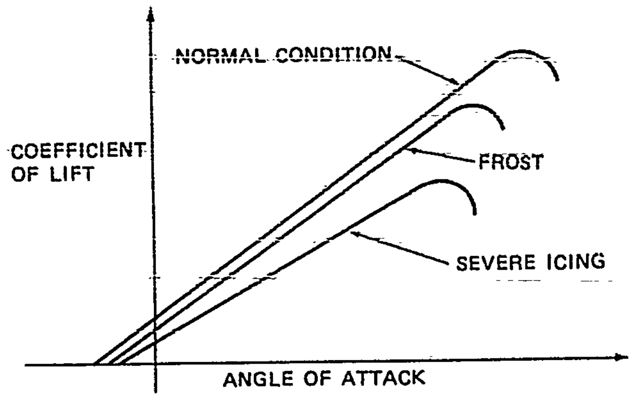


Figure F-4. Effects of Icing on Lift Coefficient

in airfoil shape can cause severe changes in airfoil effectiveness. This impression usually results in a lack of understanding of how frost may cause a loss of airplane performance.

F-14. Separation of the airflow from the surface is governed by two factors: 1) energy of the boundary layer, and 2) severity of the adverse pressure gradient. In the case of the mushroom type of ice formation, the pressure gradient is so severe that separation results. In the case of rime ice or frost, a natural buildup of the boundary layer is precluded by the severe roughness of the surface. The surface may not appear to be extremely rough to the touch but a slight amount of roughness may be quite severe for such a thin layer of air as the laminar boundary layer. When a natural buildup of the boundary layer is not possible, the energy of the boundary layer is very low and early separation is a result. The formation of frost on an airfoil will also increase the friction drag considerably and cause separation and incipient stall at a much lower angle of attack. Thus, rime ice and frost may have the same result as the leading edge mushroom type formation of clear ice, but at a lesser degree.

F-15. In the case of rime ice, clear ice, or frost, there will be an incipient stalling of the airfoil. The maximum lift coefficient will be much lower which means that the stalling speeds of the aircraft will be much higher. Also, the angle at which the airfoil will stall will be much lower. Figure F-4 illustrates these effects.

F-16. A question which always arises is – how much frost, ice, or snow must accumulate on an aircraft to create a hazard? Actual limitations defining a hazard are very hard to find. Of course, any frost, ice, or snow constitutes some degree of hazard. If operations are such that there is no ice or frost removal apparatus available, then takeoff and landing speeds should be made as high as is practical for the operations and the aircraft but rarely more than a 20% increase. Icing conditions, furthermore, may cause mechanical interference with the proper operation of flight control surfaces, particularly lift enhancing devices such as leading edge slats or slots, as well as with landing gear, antennae, and other external mechanisms. There are several references which contain more specific information concerning drag rise due to ice and frost formation, stalling attitudes, etc. The best of these are reports of the National Aeronautics and Space Administration (Washington, D. C.), Technical Notes NACA TN 2962, 2212, 1598, and 1084.

F-17. PERFORMANCE.

F-18. THRUST vs. RPM. For a typical fixed geometry axial flow turbojet engine, thrust varies approximately with rpm raised to the 3.5 power or

$$T \sim N^{3.5}$$

Where: T = thrust in pounds

N = % rpm

This can be used to write the following expression:

$$\frac{T @ 90\% \text{ rpm}}{T @ 100\% \text{ rpm}} = \frac{(90\% \text{ rpm})^{3.5}}{100\% \text{ rpm}}$$

Transposing and rearranging this relation gives:

$$\begin{aligned} T\ @\ 90\%\ \text{rpm} &= (T\ @\ 100\%\ \text{rpm})(.9)^{3.5} \\ &= .73\ (T\ @\ 100\%\ \text{rpm}) \times \sqrt{.9} \\ &= 69.4\%\ T\ @\ 100\%\ \text{rpm} \end{aligned}$$

NOTE

This expression describes the thrust vs. rpm curve fairly accurately in the upper limits of the curve only. For rpm's lower than 70%, this expression is not valid.

A good rule of thumb for thrust vs. rpm is: a one-percent loss of rpm results in a 3-½% loss in thrust. Thus:

100% rpm = 100% thrust
90% rpm = 70% thrust
80% rpm = 45% thrust

F-19. For jet engines equipped with variable nozzles, multi-spool compressors, variable stator blades, etc., a typical thrust vs. rpm relation is:

$$T \sim N^5$$

Representative approximations in this case are:

100% rpm = 100% thrust
90% rpm = 50% thrust
80% rpm = 35% thrust

F-20. PROPELLER SCARS TO SOLVE UNKNOWNS. It is sometimes important to know the speed of an aircraft or the rpm of the engine at the time an accident occurred. Formulas which provide this information for reciprocating and turboprop engines are as follows:

F-21. Reciprocating Engines.

1. To solve for ground speed when engine rpm is known:

$$\frac{\text{Engine rpm} \times N \times d}{\text{Gear ratio} \times 101.3} = GS$$

Where N = number of propeller blades
d = distance between scar marks, ft
GS = ground speed, knots

2. To solve for engine rpm when ground speed is known:

$$\frac{GS \times \text{gear ratio} \times 101.3}{N \times d} = \text{Engine rpm}$$

F-22. Turboprop Engines. Turboprop engines operate at a constant rpm, varying thrust by varying turbine inlet temperature. The approximate ground speed can be determined by assuming the engine is operating at its rated engine speed.

$$\frac{RES \times N \times d}{\text{Gear ratio} \times 101.3} = GS$$

Where: RES = Rated Engine Speed, rpm

F-23. LIFT REQUIRED DURING POSITIVE G MANEUVERS. The lift capability of the wing varies directly with the velocity squared. This can be used to write the following expression:

$$\frac{L\ (\text{req. for G desired})}{L\ (\text{at 1-G stall})} = \frac{[V\ (\text{knots, IAS req. for G desired})]^2}{[V\ (\text{knots, IAS at 1-G stall})]^2}$$

Assume 1-G stall speed = 100 knots, and you want to know the speed required to produce 2-G lift on the airfoil. In this case, L = 1 at stall and L = 2 at required G desired. Substituting these values in the expression gives:

$$\frac{2}{1} = \left(\frac{V}{100}\right)^2$$

$$V = 100 \times \sqrt{2}$$

V = 141 knots to produce a 2-G lift

F-24. LANDING AND TAKEOFF RUNS. Often it is of interest to determine the speed of an aircraft at some point during takeoff or landing roll. The matter of an exact calculation of an aircraft's speed during the roll is quite an intricate process but for purposes of approximation, several simplifying assumptions can be made. If it is assumed that the acceleration, or deceleration, of an aircraft is constant throughout the roll, the speed then varies as the square root of the distance—or, conversely, the distance varies as the square of the velocity. The following equations express this in mathematical form:

$$\frac{S_2}{S_1} = \left(\frac{V_2}{V_1}\right)^2$$

or

$$\frac{V_2}{V_1} = \sqrt{\frac{S_2}{S_1}}$$

As an example, assume that a turbojet aircraft normally would take off at 120 knots and require 3,600 feet. What would be the approximate speed of the aircraft 1,800 feet after beginning normal takeoff roll?

$$\frac{V_2}{V_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\frac{V_2}{120} = \sqrt{\frac{1{,}800}{3{,}600}} = \sqrt{.5} = .707$$

$$V_2 = (.707)\,(120)$$

$$V_2 = 85 \text{ knots}$$

This approximation would be relatively accurate for a turbojet aircraft since the acceleration is fairly constant throughout the takeoff roll. In applying this approximation to the reciprocating engine driven aircraft, the velocity computed would be less accurate since the propeller driven aircraft has a higher acceleration in the low speed range than in the high speed range of takeoff roll. However, the approximation could be applied, then the result revised upward as experience dictates.

F-25. In applying these equations to landing roll, it must be remembered that the distance ratio $\frac{S_2}{S_1}$ will be the ratio of the distance between the aircraft and stopping point to the normal landing roll distance. As an example, assume that an aircraft touches down at 100 knots and requires 2,800 feet to stop with the use of braking. What would be the approximate speed of the aircraft 2,100 feet after a normal touchdown?

$$\frac{V_2}{V_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\frac{V_2}{100} \sqrt{\frac{700}{2{,}800}} = \sqrt{.25} = .5$$

$$V_2 = .5(100)$$

$$V_2 = 50 \text{ knots}$$

Of course, the application of this approximation for computing speed V_2 during landing roll-out will be in error only by the amount which the deceleration is nonuniform. In other words, the approximation would be in great error when reverse thrust or drag-chutes are used for some portion of the landing roll.

F-26. Overspeed Touchdown. It can be proven that a ten-percent velocity increase at touchdown will result in a 21% increase in landing distance. The following expressions can be used to approximate the landing distance required for an overspeed touchdown:

1. $$\frac{S_2}{S_1} = \left(\frac{V_2}{V_1}\right)^2$$

Where: S_1 = Landing distance at normal touchdown velocity = 4,500 ft.

S_2 = Landing distance at excessive touchdown velocity.

V_1 = Normal velocity at touchdown = 120 kts.

V_2 = Velocity at touchdown = 132 kts (110% X 120 kts).

By substitution:

$$\frac{S_2}{4500} = \left(\frac{132}{120}\right)^2 = \left(\frac{11}{10}\right)^2 = \left(\frac{121}{100}\right) = 1.21$$

$$S_2 = (1.21)(4500) = 5{,}445 \text{ ft.}$$

Therefore, the total travel at overspeed is 5445 feet, which is 21% greater than normal landing distance.

2. Speed at Touchdown:

$$\frac{V_2}{V_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\frac{V_2}{120} = \sqrt{\frac{5445}{4500}} = \sqrt{\frac{121}{10}} = \frac{11}{10} = 1.1$$

$$V_2 = 1.1\ (120) = 132 \text{ kts.}$$

132 - 120 = 12 kts. overspeed

F-27. Effects of Wind on Takeoff and Landing Distances. This is extremely important. The effect can be estimated by the following equation:

$$\frac{Sw}{So} = \left(1 - \frac{Vw}{V}\right)^2$$

Where. Sw = Landing or takeoff distance when a headwind is blowing, feet,

So = Landing or takeoff distance with zero headwind, feet,

Vw = Wind speed, knots,

V = Aircraft landing or takeoff speed, knots

If the wind velocity is 30 knots and the landing speed is 120 knots as in the previous problem,

$$\frac{Sw}{So} = \left(1 - \frac{30}{120}\right)^2 = (1 - .25)^2 = .565$$

a reduction of 44 percent from the landing or takeoff roll without wind, certainly enough to be of concern to the pilot. A good rule of thumb is a wind of one-percent of the takeoff speed will cause a two-percent change in distance in the direction of the wind. The same holds true for landing.

F-28. Refusal Speed. With the advent of high-performance aircraft requiring long distances for takeoff and landing, the matter of speeds for safely aborted takeoff has become more important. The highest speed reached during takeoff which will allow a safe stop on the remaining runway is referred to as the refusal speed. If the aircraft is above the refusal speed and an emergency is declared, the aircraft is committed to takeoff (if possible) or to make an unsafe stop. Refusal speeds given for various flight conditions account for the use of all braking capabilities possible. However, for multi-engine aircraft which have reverse thrust available, refusal speeds are usually computed assuming partial power loss such as only two engines available for reverse thrust in a four-engine aircraft. If the pilot of a four-engine aircraft should decide to abort takeoff due to loss of power from one engine, only two of the remaining three powerplants could be used for reverse thrust in order to maintain symmetry of power.

F-29. If the performance of the aircraft and the length of runway available are known, the refusal speed can be approximated. The distance traveled in accelerating up to the refusal speed plus the distance required to slow down from the refusal speed must equal the runway available. If uniform acceleration is assumed, the following equation will approximate the ratio of refusal speed to takeoff speed.

$$\frac{Vr}{V_{to}} = \sqrt{\frac{Ra}{S_{to} + S_1\left(\frac{V_{to}}{V_1}\right)^2}}$$

Where: V_r = Refusal speed,

V_{to} = Takeoff speed,

R_a = Runway available,

S_{to} = Takeoff distance,

S_l = Landing distance (at same weight as V_{to} and S_{to} using all available braking action),

V_l = Landing speed (at same weight as V_{to} and S_{to})

1. The refusal speed can also be found by graphical means as shown in figure F-5.

2. As the numerical example, assume that the following information is given and it is required that the refusal speed (V_r) and refusal distance (S_r) be computed.

V_{to} = 120 knots

S_{to} = 4,000 feet

V_l = 110 knots

S_l = 5,000 feet

R_a = 8,100 feet, no wind

$$\frac{V_r}{V_{to}} = \sqrt{\frac{Ra}{S_{to} + S_l\left(\frac{V_{to}}{V_l}\right)^2}}$$

$$\frac{V_r}{120} = \sqrt{\frac{8100}{4000 + 5000\left(\frac{120}{110}\right)^2}}$$

$$\frac{V_r}{120} = \sqrt{.81} = .9$$

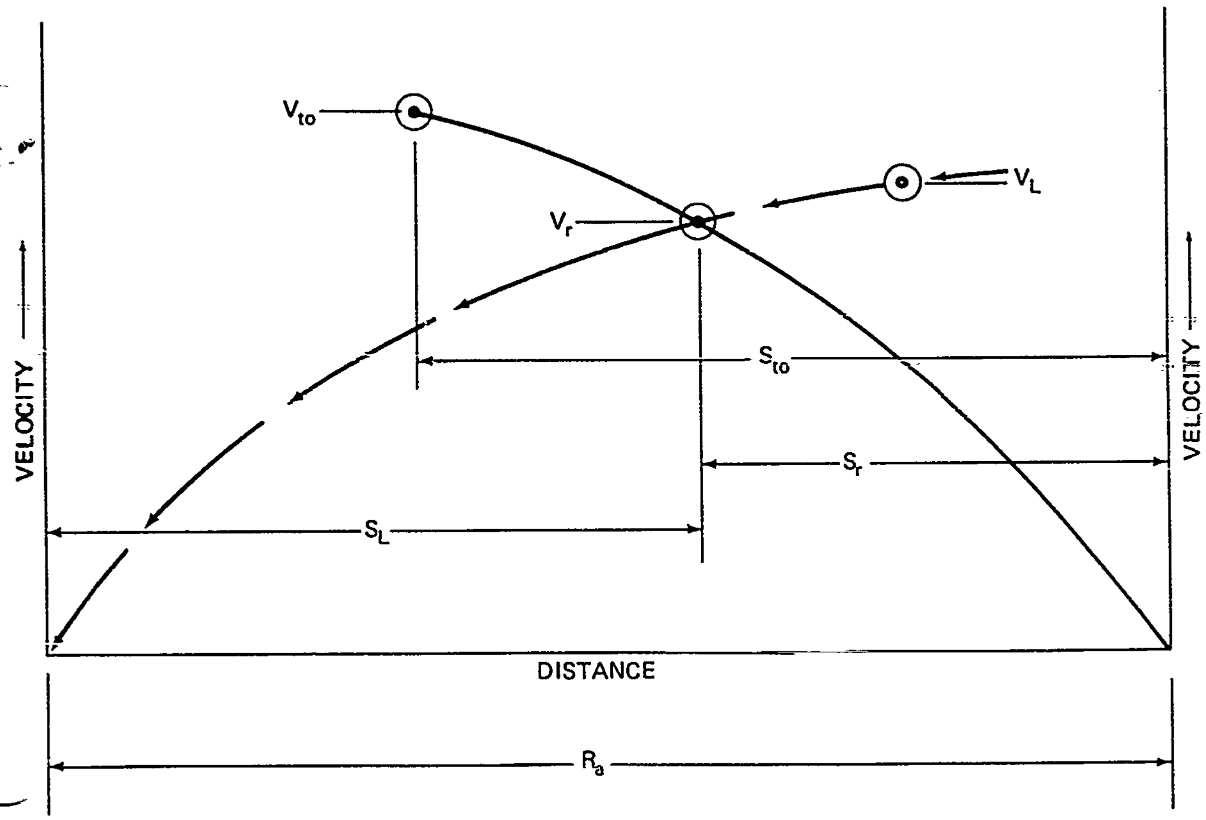


Figure F-5. Takeoff Resufal Speed

$$V_r = (.9)(120)$$

$$V_r = 108 \text{ knots}$$

As the distance varies as the square of the velocity, the refusal point on the runway may be found by:

$$\frac{S_r}{S_{to}} = \left(\frac{V_r}{V_{to}}\right)^2 = .81$$

3. Indicators or markers could be placed at the refusal point on the runway to serve as an additional check. If the refusal speed is gained by the time the refusal point is reached, there is then proof that the aircraft is accelerating normally.

4. Whenever operating weights, atmospheric conditions, or runway lengths are altered, a new refusal speed should be found accounting for these factors.

5. Remember that these figures are approximate and do not allow for decision time, shutdown time, and brake application time.

F-30. REGION OF REVERSE COMMAND. By examination of a typical speed-power required curve it is seen that within a certain speed range it is possible for an aircraft to maintain either of two speeds for a given power setting. In other words, there are two points at which power available equals power required. Flight at either of these points will differ with respect to airpseed and angle of attack – and one other matter referred to as speed-power instability.

F-31. As shown in figure F-6, the power required for flight is high at stall speed and steadily decreases with airspeed until the point of minimum power required is reached. At speeds above the speed for minimum power required the power required for flight begins to increase. The speed range above the speed for minimum power required is called the region of normal command since an increase in airspeed requires an increase in power. In this speed range, parasite power re-

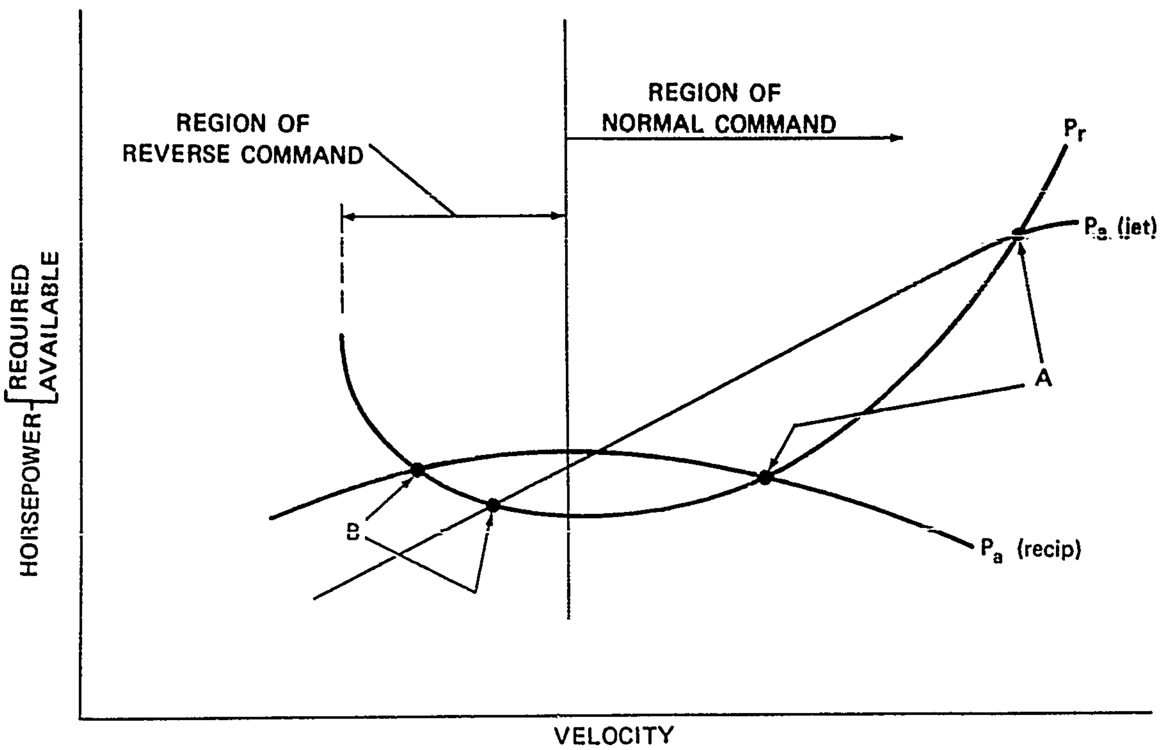


Figure F-6. Region of Reverse Command

quirements predominate. The speed range between stall speed and minimum power required speed is called the region of reverse command since an increase in airspeed will result in a decrease in the power required for flight. In this speed range induced power requirements predominate.

F-32. To investigate this matter of speed-power instability, consider the case of an aircraft with the power available as shown in figure F-6. This could be the case of an aircraft with all powerplants operating at power settings less than full throttle or a multi-engined aircraft during an emergency with engines out and the remaining powerplants operating at near full power. With the particular power available, the aircraft should be able to maintain steady level flight at either point A or point B since at these points power available equals power required. Flight at point A offers no problem in that the speed-power relationship would be favorable, tending to hold the aircraft at point A. If a gust or control movement were to place the aircraft at an air-speed higher than A the power required would be greater than the power available and the aircraft would tend to slow back down to point A. The aerodynamic forces on the airplane would help to reestablish the airspeed at A. If the aircraft were placed at an airspeed lower than A by some disturbance, the power available would be greater than the power required, tending to accelerate the aircraft back to point A. Hence, flight at point A would be very stable with the aircraft tending to hold its airspeed and could easily be flown "hands off." Flight at point B would offer some problem because flight is being conducted in the region of reverse command. If a gust or control movement were to place the aircraft at an airspeed slightly higher than B, the power available would be greater than the power required and the aircraft would tend to accelerate away from point B. Of course, the aerodynamic forces on the aircraft are resisting this change in airspeed, but for most aircraft the resulting airspeed variation would be large if the aircraft was flown "hands off." If the aircraft was placed at a speed slightly lower than B by some disturbance, the power required would be greater than the power available and the aircraft would tend to continue losing airspeed. This is the speed-power instability experienced by an aircraft being flown in the region of reverse command and is often referred to as flight on the backside of the power curve. Flight in this region will require close and constant attention to airspeeds and power settings since any deviation in airspeed tends to bring about even larger deviations.

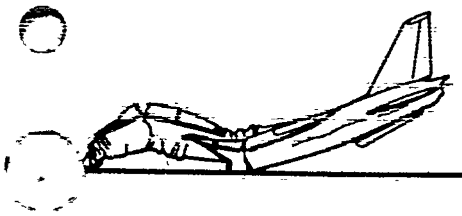
F-33. There are only a few particular conditions of flight at altitude which require flying in the region of reverse command and, in general, flight in this region should be avoided if possible. Of course, every aircraft must be flown through this region after takeoff and on final approach to landing. Other potentially dangerous circumstances which can lead to flying in the region of reverse command are:

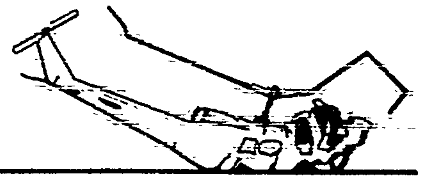
1. Extremely high weight condition,
2. Loss of power available,
3. Pilot's lack of attention concerning airspeeds and power settings.

F-34. Again referring to figure F-6, assume the curves may be applied to the case of a four-engine aircraft during an emergency landing with two engines out. During final approach, assume that with the remaining two engines at full power the speed is established at point B. If the pilot allows the airspeed to drop below point B, the only way the airspeed will be regained is by a sacrifice of altitude. If the speed drops below point B and an attempt is made to hold altitude, the aircraft will continue to decelerate and approach a stall.

F-35. Under normal landing conditions, when excess power is available during an approach, any flight in the region of reverse command should be made with two primary rules in mind. They are to control the altitude with the throttle and the airspeed with the stick. Flight in the region of reverse command in itself is not dangerous and can be accomplished safely. However, the matter of speed-power instability is to be reckoned with and any variations in air-speed allowed, coincident with a loss of power available, will present dangerous circumstances.

F-36. Turbojet aircraft flying in the region of reverse command can also be said to be flying on the backside of the drag curve. The region of reverse command extends from the stall speed to the minimum drag speed. Flight in the region of reverse command may be more difficult even under normal power conditions since the situation is aggravated by the relatively low acceleration of the turbojet engine and the relatively large speed range over which the reverse command is in effect.





APPENDIX G.

TECHNICAL ASSISTANCE

G-1. GENERAL.

G-2. In those aircraft accident investigations where determination of cause factors appears to be beyond the technical capabilities of the members of the aircraft accident board, technical assistance is available to the board upon request of the controlling custodian via the cognizant immediate superior in command. Complete instructions regarding the correct procedure for requesting technical assistance are promulgated in the OPNAV instruction governing aircraft accident reporting procedures.

G-3. Sources of technical specialists for assistance in aircraft accident investigations include airframes manufacturers, aircraft engine manufacturers, aircraft component and accessory manufacturers, naval air rework facilities, aeromedical laboratories, National Bureau of Standards, and naval laboratories and development centers. Suggestions for the best utilization of these sources of assistance are listed in the remaining paragraphs this section.

G-4. AIRFRAME AND ENGINE MANUFACTURERS.

G-5. Various factory representatives are stationed at all naval air stations–especially where large numbers of a particular type of aircraft are operating. Time and time again, these representatives have been of most valuable assistance to the members of aircraft accident boards. They are anxious to be called upon for assistance. During the course of an investigation they will be of the most valuable service in the following ways.

1. To assist in the identification of parts during the aircraft wreckage reconstruction phase.

2. Providing information as to the latest changes in production aircraft by Bureau number.

3. Identification of the subcontractor of aircraft components and accessories and liaison with the subcontractors through the prime contractor.

4. Information as to the functioning of aircraft systems.

5. Direct liaison with the manufacturer.

6. Specific technical information stemming from design, manufacture, and assembly problems.

7. Access to independent testing laboratories through the manufacturer.

G-6. NAVAL AIR REWORK FACILITIES.

G-7. Each naval air rework facility is designated as a depot activity for certain types of aircraft, engines, and equipment. (See OPNAVINST 4790.2A for designated NARF for a specific aircraft, engine, or equipment.) As such, by their possession of specific facilities, tools, and personnel, they maintain a certain capacity for disassembling, inspecting, and testing specific aircraft and aircraft components. They do not possess the facilities for detailed engineering, detailed testing, and laboratory analysis as does the manufacturer. Generally, they possess adequate facilities for the testing of standard items of Government-furnished equipment. They also maintain specialized testing capacity of items common to all types of aircraft. They will usually be of the most service to an aircraft accident board, for specific requests such as:

1. Safety engineering investigations.

2. Check, test, operation, and type of procedures for which they are the assigned depot activity.

3. Determination of type failures.

4. Examination and analysis of recovered instruments.

G-8. It is important that the depot activity be furnished the complete units for disassembly. Engines sent to depot for a safety engineering investigation should include all associated system components.

G-9. Proper procedures for requesting technical assistance or a safety engineering investigation include a specific message request to the cognizant systems command agency to determine the cognizant rework facility and shipping instructions. In these cases, material receipt will be obtained from the rework facility. On completion of the investigation, the material will be returned to the reporting activity, scrapped, or turned in to the naval supply system, in which case a copy of the document showing disposition will be forwarded to the reporting activity.

G-10. Rework facilities will place such material at the head of any existing line for disassembly and inspection. Extraordinary effort will be made to complete the work and submit the safety engineering investigation report in the shortest possible time. The report will be sent to the originating activity and such other addresses as may be designated on the Fur Screen Tag, with copies to the Commander, Naval Air Systems Command and to the Naval Safety Center. Reference must be made to model aircraft, Bureau number, date of occurrence, and reporting activity aircraft accident, incident, flight hazard, or ground accident report serial number.

G-11. Technical assistance rendered to the aircraft accident board by technical specialists obtained under these provisions is advisory only in nature, and in no case will the technical specialists be considered as members of the board, nor will the board be required to accept any conclusions or decisions arrived at by the technical specialists.

CAUTION

The following considerations must be adhered to in order that maximum benefit is derived from the safety engineering investigation.

1. Do not attempt the disassembly and reassembly of components prior to sending to the NARF for safety engineering investigation.

2. Many parts requiring safety engineering investigations are lost in shipment. Be sure to send all shipping data to the NARF in order to facilitate the recovery of missing shipments, and to mark shipment well.

3. Aircraft engines shipped to NARF for safety engineering investigation must include the necessary accessories (fuel pumps, carburetors, etc.).

4. In the history of the failed part or component, include as much data concerning the accident as possible. If at all feasible, have a

board member accompany the components to the NARF.

G-12. AEROMEDICAL LABORATORIES.

G-13. Technical assistance for aircraft investigation boards may be necessary when a particular phase of the accident under investigation requires specialized talents or laboratory facilities for proper analysis. The following listing includes naval facilities and their principal related specialized interests.

1. Naval Air Development Center, Warminster, Pennsylvania–Acceleration problems, structures, and cockpit instrumentation.

2. Naval Aviation Equipment Laboratory, Philadelphia, Pennsylvania–Safety, survival, and protective equipment, human engineering design problems.

3. School of Aviation Medicine, Pensacola, Florida–Aviation medicine and psychological problems.

4. Naval Safety Center, Norfolk, Virginia–Accident investigation, statistical assistance, and technical information.

5. Naval Electronics Laboratory, San Diego, California–Human engineering.

6. National Naval Medical Center, Bethesda, Maryland–Analysis of blood and tissue specimens.

7. Armed Forces Institute of Pathology, Washington, D.C.–Analysis of blood and tissue specimens.

8. Armed Forces Medical Laboratory Facilities–As outlined in BUMED INST 6200.1 - Pathological assistance.

G-14. NATIONAL BUREAU OF STANDARDS.

G-15. In specialized cases where the time and effort is merited, special studies of controversial components can be requested of the Bureau of Standards. Their capabilities include chemical and physical analysis of paint, fuel, oxygen, oils, metals, rubber, synthetics, and numerous other substances common to the manufacture and operation of aircraft. These facilities are available through the technical bureau concerned.

G-16. NAVAL LABORATORIES AND DEVELOPMENT CENTERS.

G-17. Members of aircraft accident boards will seldom be required to request assistance from these sources. However, they should know that special assistance is available from the various ordinance, photographic, electronic, material, etc., research and development centers through requests of the technical bureau concerned.

G-18. NAVAL SAFETY CENTER.

G-19. The Naval Safety Center is an excellent source of technical and statistical assistance in accident investigations. Trained and experienced investigators from the Naval Safety Center can aid in all phases of the investigation as well as provide technical and statistical information. Reports from previous accidents are stored on a computer at the Naval Safety Center, and the aircraft accident board can request a printout of data on similar accidents for use as a guide to potentially fruitful avenues of investigation. This can be especially valuable in hole-in-the-ground accidents, and accidents where there is no wreckage available.

APPENDIX H.

CHARACTERISTIC FAILURES IN METAL

H-1. FATIGUE FAILURES

H-2. Fatigue is simply the progressive failure of a part under repeated loading. Fatigue is not a new problem. In fact, it dates back to the time when metallic materials were first used for structural components. As early as 1858, Wohler, one of the earliest researchers in the field, concluded after conducting many tests, "Wrought iron and steel will rupture at a stress not only less that the ultimate static strength of the material but even less than the elastic limit, if the stress is repeated a sufficient number of times." This finding is as true today as it was then.

H-3. IMPORTANCE OF FATIGUE IN AIRCRAFT ACCIDENT INVESTIGATIONS. There are a number of reasons why fatigue is assuming more and more importance in aircraft design and operation. In the early days of aircraft design, maneuver loads were the only ones used to design the airframe. Gust loads were completely disregarded in design until the thirties. The strength that an aircraft had to have in order to withstand the intentional maneuvers, such as sharp turns and pullups from a descending flight path, was adequate to cover gust loads. As transports grew larger, they were being maneuvered more cautiously, and the design maneuver loads were correspondingly reduced. It then became necessary to include in the design an investigation of the strength under the load imposed by single but severe vertical gusts. The gust design requirement is the one previously explained.

H-4. Unsatisfactory service experience in aircraft has brought the fatigue problem to high priority, especially that aspect of the problem dealing with the cumulative effect of repeated gust loads. The emergence of fatigue as a design problem in airframes stems from the general trend of development in aviation. Aircraft are becoming ever larger, heavier, and more expensive. Flight speeds are ever increasing. Longer life and higher speeds mean more miles covered; consequently, more gusts encountered. Higher airplane speeds mean higher loads for a given gust velocity. More refined methods of design for static strength bring about a reduction of the so-called hidden factors of safety. Finally, development in materials has brought about improvements in the static strengths of the materials, but unfortunately, without commensurate improvements in the fatigue properties.

H-5. RECOGNITION OF FATIGUE FAILURES. The term fatigue failure is normally applied to those fractures that are caused by repeated loading at a calculated stress considerably lower than would be required to cause failure under a single load application. The complete story of a fatigue failure is in almost all cases set forth on the face of the fracture. In other words, much valuable information relative to the magnitude and direction of loading and to the presence or absence of stress concentrations can be developed through a careful study of the fractured surfaces. Interpretation of the fracture, however, may not always be a simple matter, because each case may be influenced by many variables. Some contributing factors such as decarbonization can only be verified by laboratory examination. In many cases, on the other hand, the cause can be pinpointed in the field by careful study of the fracture alone.

H-6. Fatigue failures occur without perceptible ductility, as contrasted with static failures where considerable ductility or necking down generally takes place. This distinction is often helpful in isolating a part which has failed from fatigue. All brittle failures, however, are not necessarily fatigue failures, and this feature must be used with other features to be described before a final determination is made. In addition, most fatigue failures (some torsion fatigue excepted) occur on planes which are at right angles or nearly at right angles to the loading. On a large number of parts, the fatigue plane will be perpendicular to the axis of the part, and in the fatigue area the fracture will generally be in one plane. Irregular fractures, therefore, when the fracture slips from one plane to another and when these planes are very much different from a plane perpendicular to the loading or to the axis of the part, are very probably not fatigue fractures although close examination is often required to see if some small area on the fracture does not conform to the basic requisites. The two features of a fatigue fracture referred to in this paragraph are extremely useful in ferreting out a fatigue failure from a large number of failures. In fact, in those cases when the fractured surfaces are mutilated from subsequent damage, these features may be the only ones available to distinguish between fatigue and static failures. Having both halves of the fracture available so that the sections can be carefully fitted together and studied is almost a necessity in making determinations of this type.

H-7. As indicated previously, the most valuable information is contained on the fracture surface itself. The actual fatigue fracture surface is composed of two distinct regions: one smooth and velvety – the fatigue zone, and the other coarse and crystalline – the instantaneous zone. (See figure H-1.) The smooth velvety appearance of the fatigue zone is caused by the rubbing of the mat-

Figure H-1. Typical Fatigue Fractures

...g surface as the crack opens and closes under repeated loading. The coarse appearance of the instantaneous zone has given use to the erroneous "crystallization theory." For many years, people examining fatigue fracture or in discussing it ...e accustomed to say that the part had "crystallized." Metallurgically, it is untrue that this part of the metal crystallizes under fatigue loading.

H-8. The first task, then, in searching out a fatigue failure is to look for the two distinct types of zones on the fracture–the fatigue zone and the instantaneous zone. In many fractures, more than one fatigue zone will often be found, indicating that several fatigue cracks had developed and were progressing at the time of the final failure. In each fatigue zone, the origin of the fatigue crack can be found by locating the center of radiation of the fatigue waves. These fatigue waves are variously known as "clamshells," "oyster shells," or "stop marks," and are found in almost every service fatigue failure. It should be noted here that in some instances, notably ...ere certain aluminum alloys are involved, the ...gue progresses without leaving distinctive wave markings, although in these cases, the fatigue area can be identified by its smooth, rubbed, velvety appearance. In some cases, secondary techniques such as examining for absence of ductility and single failure planes approximately perpendicular to the loading or for the presence of stress concentration must be used to isolate a fatigue fracture. Any suspicious or dubious fractures should be referred to a specialist for confirmation.

H-9. The many wave lines or bonds in a typical service fracture are caused by various degrees of rubbing as the crack either stops for certain periods or progresses at a varying rate under different stress levels. For this reason, the term stop marks as it is applied to the fatigue waves is perhaps more pictorial than the other two commonly ...d expressions since it indicates a hesitancy in ...rack progression. Laboratory fatigue speci... ...t failures very seldom show stop marks because the loading is almost always at a constant level.

...0. In the following sections, the appearance of the fatigue fracture under various types of loading is illustrated, and the information that can be learned from an analysis of the markings is briefly discussed. It should be reiterated that fracture analysis as such is a complex problem and that this handbook cannot hope to cover all of the countless variations. However, knowledge of the material in the following sections should enable the investigator to recognize and diagnose the majority of service fatigue failures that he is likely to encounter.

H-11. BENDING FATIGUE. Bending fatigue failures can be divided into three general classifications according to the type of bending load imposed. These three types are one-way bending, two-way bending, and rotary bending. Most severe bending fatigue will fall into one of these categories.

H-12. One-way bending results when a fluctuating bending stress is imposed on a part already loaded with a steady stress–either tension or compression. Under this type of loading, the stress at one point on the outer ecge of the piece generally is at a maximum and a fatigue crack will start here if the stress is above the endurance limit and if it is repeated long enough (see figure H-2). Under two-way bending loading, the stress on both sides of the neutral axis is the same and, when the stress level and number of loadings are of the right order as before, cracks will start on either side of the part and progress toward the center (see figure H-3). Rotary bending occurs when a part is rotated while under a bending loading. A typical example of rotary bending would be an engine crankshaft or a railroad axle under service loading (see figure H-4).

H-13. The stress level affects the relative size of the fatigue and instantaneous zones. When the stress level is low, the fatigue zone is large and vice versa. Stress concentration affects the general curvature of the fatigue waves or stop marks. In all cases of fatigue under bending loading, the radius of curvature increases as the crack progresses inward. As the stress concentration increases from a value of 1.0 (no stress concentration) up to some high value, the curvature of the stop marks increases markedly and at the very high stress concentration, the curvature becomes con-

Figure H-2. One-Way Bending Fatigue

vex instead of concave. The displacement of the stop marks shown for the rotary bending case is associated only with this loading and is known as crack slip. This slip or turning around is against the direction of rotation and this point can be used to determine the rotation direction.

H-14. These general features, then, can be used to determine the type of bending, loading applied, and, qualitatively, the stress level and presence or absence of stress concentrations. If the cross section under consideration differs widely from a symmetrical section, the actual significance of the markings as related to stress level and stress concentrations may be somewhat altered, but, in general the same reasoning still applies.

H-15. TENSION FATIGUE. Because of initial eccentricities in a part or because of eccentric loading, pure tension loading as such rarely occurs in service. Usually some amount of bending accompanies tension on axial loading. However, enough fatigue failures under predominantly axial loading do occur in service to warrant learning how to distinguish these failures from bending and torsional failures. Tension fatigue failures can generally be recognized by the manner in which the crack has progressed into the part. Parallel or constant curvature stop markings are characteristic of fatigue failures resulting from straight tension loading. As in bending fatigue failures, the relative size of the fatigue zone and the instantaneous zone can be used as a measure of the stress level which produced the failure.

H-16. TORSION FATIGUE. Torsion fatigue failures occur in either of two basic modes: (1) helical, at approximately forty-five degrees to the axis of the shaft, along the plane of maximum tension, or (2) longitudinal or transverse to the axis of the shaft, along the planes of maximum shear. Fatigue stop markings may not always be found on the fracture, and secondary means suc' as absence of ductility and observing the angle (the failure plane must often be used to identify failures of this type. Transverse fractures are frequently very smooth from the rubbing of the two halves of the fracture before final separation and this characteristic can be used to isolate this type. In many service torsion fatigue failures, the initial crack will start in one plane and then slip off into another. Helical fractures generally occur when stress concentrations are present, while longitudinal or transverse fractures usually indicate the absence of stress concentrations. In searching out torsion fatigue failures, the investigator is usually aided by the knowledge that torsion loading is present in the service application. In this regard, torsion fatigue should be suspected when examining failures of crankshafts, turbine shafts, compressor drive shafts, flap drive torque tubes, coil springs, splined shaft members, etc. Figure H-5 presents in the various ways in whic torsion fatigue failures are found in service.

H-17. STATIC FAILURES.

H-18. For the purpose of this handbook, a static

Figure H-3. Two-Way Bending Fatigue

failure is defined as a failure resulting from one or a small number of load applications. The failure is characterized by permanent distortion or rupture of the member as a result of stresses in excess of the yield point of the material. This type of failure can be recognized by yielding over a considerable portion of the member in the region of the failure. This phenomenon is commonly referred to as necking in the failure of a conventional tensile-test specimen.

H-19. OCCURRENCE. Static failure will occur when loads in excess of the design loads are imposed on the aircraft or some component of the aircraft. In flight, this can happen when the aircraft is maneuvered too severely or at too high a speed. In landing or on the ground, this can occur when the aircraft is landed too hard or when the aircraft is taxied over an obstruction. The damage that results when an aircraft strikes the ground is of the static type, with impact loading being an important consideration.

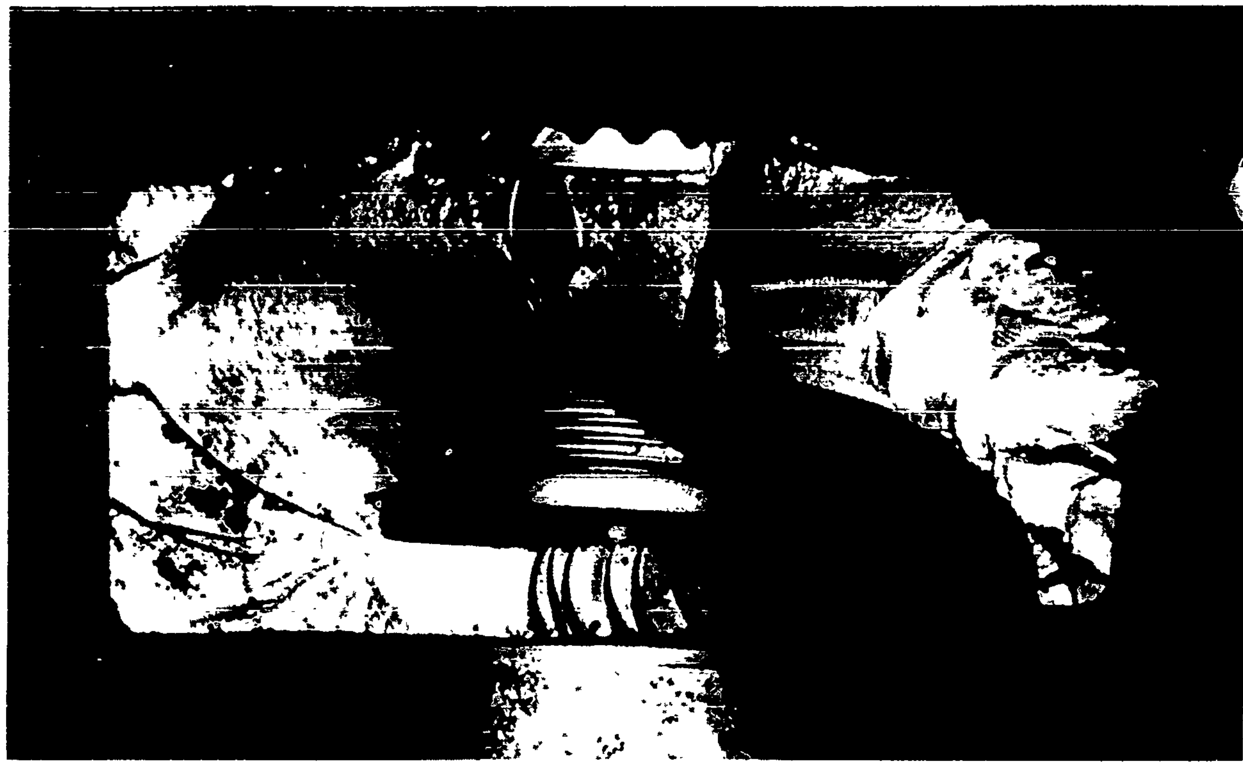


Figure H-4. Rotary Bending Fatigue

H-20. RECOGNITION OF STATIC FAILURES. The yielding or necking effect found in most metal fractures is an indication of a static type of failure. Detailed examination of the deformation will disclose indications of the type of loading (bending, tension, etc.) and the direction of loading (see figure H-6). In most cases, the two halves of the fracture will mate with one another or can be recognized as a pair.

H-21. TENSILE FAILURE. In a tensile failure, the fractured surface is usually made up of a series of planes inclined approximately forty-five to sixty degrees to the direction of loading. In a thin part, such as sheet metal, there may be only one such inclined plane. Considerable local deformation or necking with a reduction of cross-sectional area is also generally evident. If the fracture is pure tension alone, the two halves of the fracture will part cleanly and there will be no evidence of rubbing.

H-22. Tensile tearing occurs when the sheet tears under tensile forces in the plane of the sheet or member. This type of fracture is quite common. Examination of the fracture will disclose "herringbone" marks with the head of the herringbone pointing back to the origin of the tear.

H-23. COMPRESSION FAILURE. Compression failures occur in two general forms block compression and buckling. Block compression is generally found in heavy short sections, whereas buckling is found in long, lighter sections. When buckling occurs locally, it is referred to as crippling. When it occurs in such a way that the whole piece buckles, it is referred to as column buckling. Local buckling and column buckling are easily recognized since the part in all cases is bent from its original shape (see figure H-7). In block compression failures, the piece separates on oblique planes as in tension, except that there is rubbing of the two halves of the fracture during separation. In addition, in some materials there is a local increase in cross-sectional area where the material has yielded.

H-24. BENDING FAILURE. Bending is resisted by tensile forces on one side of the member and by compression on the opposite side. The appear-

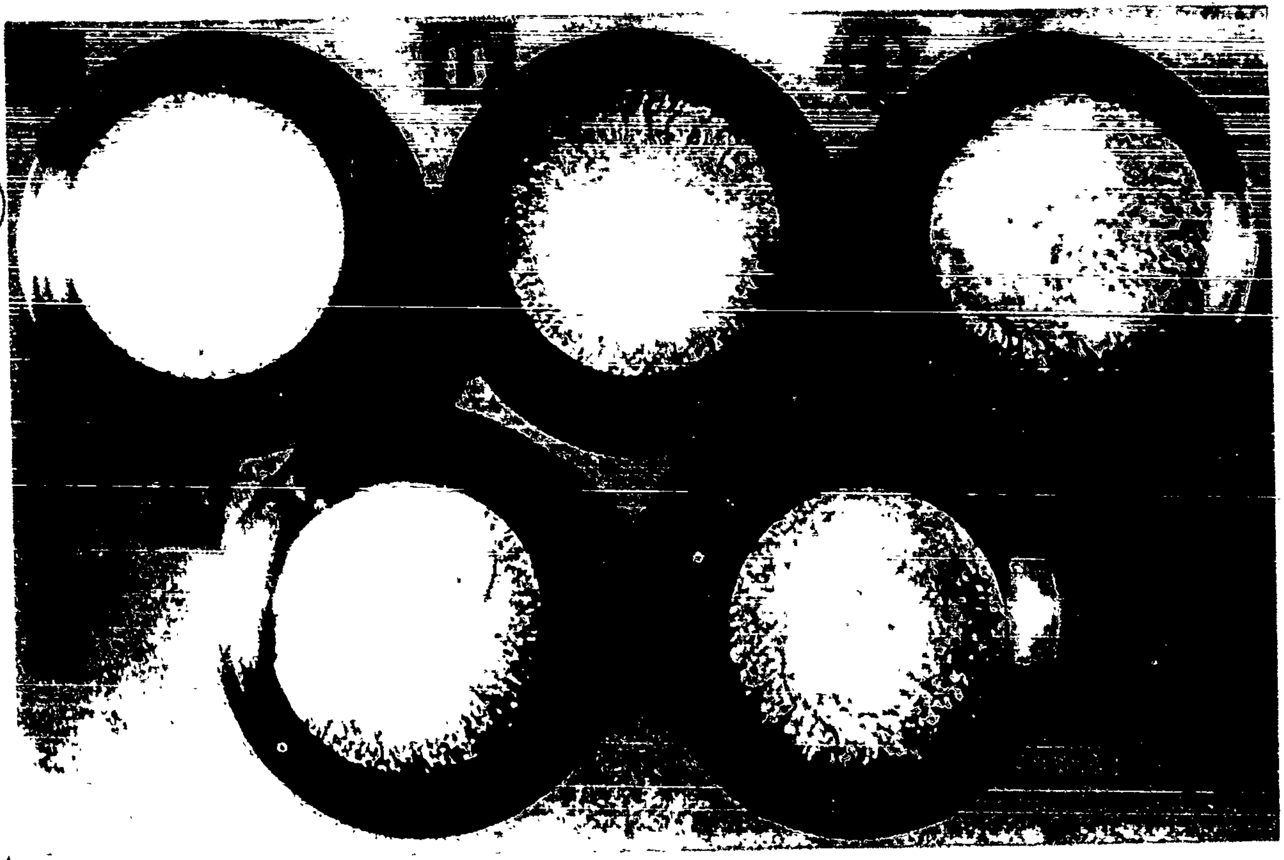


Figure H-5. Typical Torsion Fatigue Failures

ance of the fracture in the respective areas is as outlined under tension and compression. The direction of the bending moment causing failure can always be determined from local distortion in the fracture area. As the part finally separates, lipped edges may be found on the inside or compression face of the fracture (see figure H-8). This lipping occurs because after the initial tensile failure, the final failure on the compression side may be in shear rather than in compression.

H-25. SHEAR FAILURE. As in compression failures, shear failures can occur in two distinct ways—block shear and shear buckling. In the former type of failure, the two halves of the fracture will slide across the other and the fracture will appear rubbed, polished, or scored. The direction of scoring will give a clue to the direction of the applied shearing force. Shear buckling generally occurs in thin sheet metal such as a wing skin or spar webs. The sheet will buckle in a diagonal fashion and the direction of force application can be told from the appearance of the buckle (see figure H-9). When rivets, screws, or bolts fail in shear, it is usually accompanied by elongation of the hole and there will appear behind the rivet a new moon or crescent shape open space. This result can be used to determine the direction of the shearing force.

H-26. Shear failures in sheet metal, and occasionally in heavier sections, generally are in the form of shear tearing. Shear tearing occurs when the applied forces are acting out of the plane of the sheet. These failures are characterized by a lipping of material on the edges of the sheet and by scoring lines on the fractured surface. The concavity of the scoring can be used to tell the direction of tearing. The direction of tearing is from convex to concave. Sometimes if there is a heavy paint film, the saw-toothed breaking of the paint film can be used to tell the direction of tearing.

H-27. TORSION FAILURE. Since torsion is a form of shear, the failure from torsion overload

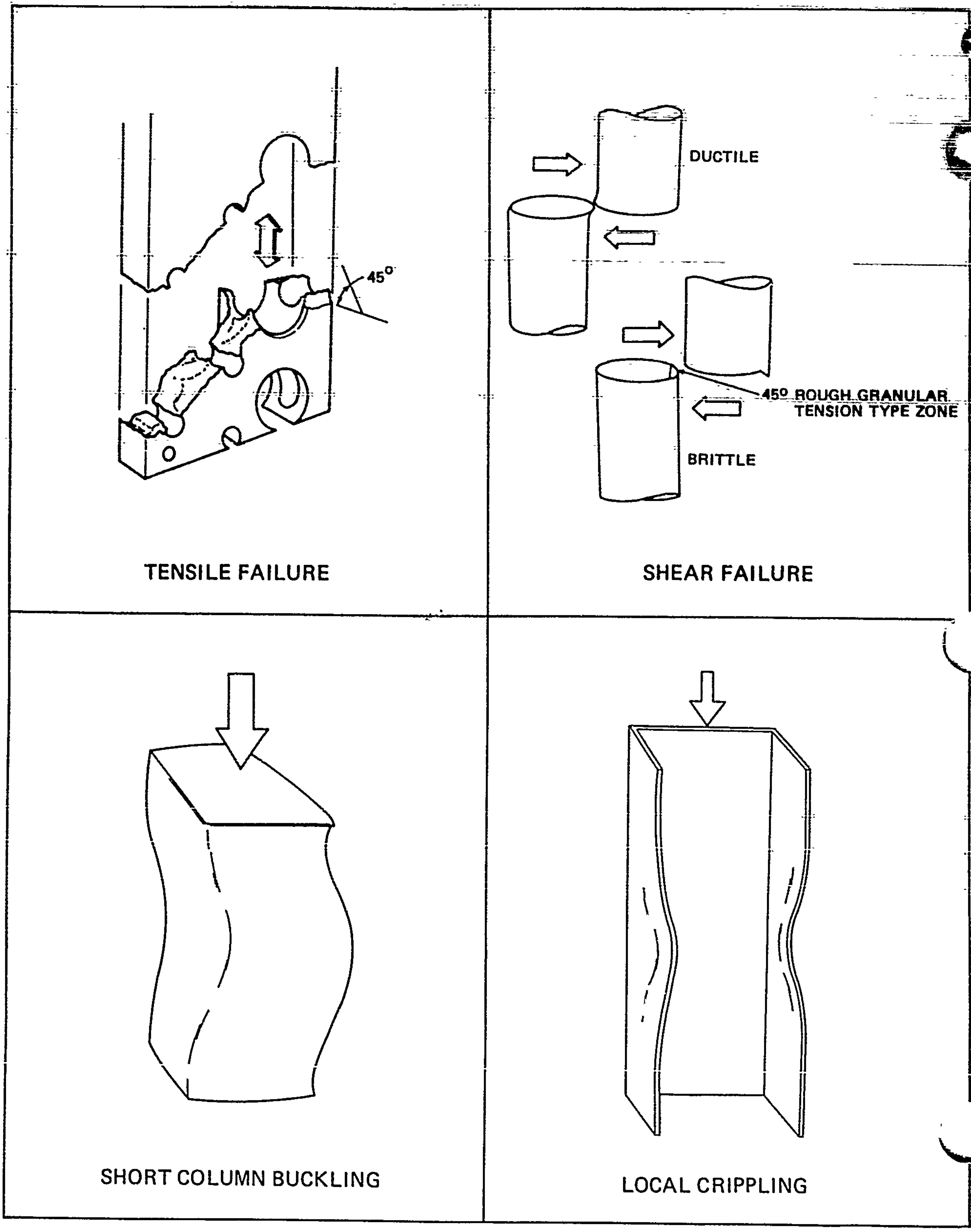


Figure H-6. Static Failures

Figure H-7. Buckling Compression Failure

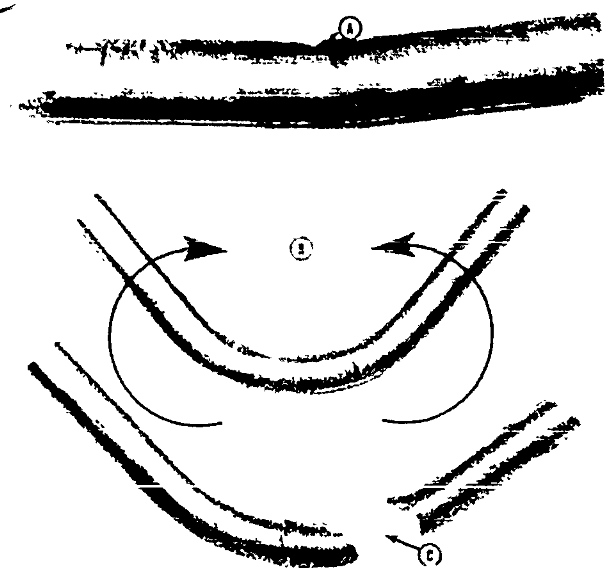


Figure H-8. Bending Failure

will be somewhat similar to the shear failure. Evidence of the direction of torque can be seen on the fractured surface by observing the scoring marks. Most parts retain a permanent twist and this can be used as an indication. In tubing mem-

Figure H-9. Shear Buckling Failure

bers or a large open section like the wing, torsion failures often occur as instability failures in a buckling manner. Again the direction of twist can be determined by close examination of the buckle (see figure H-10).

H-28. IMPACT LOADING.

H-29. Impact loading may be considered as a special case of static loading where the speed of load applications affects the magnitude of the load. Unusually high forces can be developed under impact loading. Materials which fail in a ductile manner under normal static loading can be made to fail in a brittle manner if the rate of loading is high enough. It should be remembered that even when an aircraft strikes the ground at high speed, because of elasticity in the aircraft structure and the load absorbing characteristics of the ground, many parts are loaded at rates con-

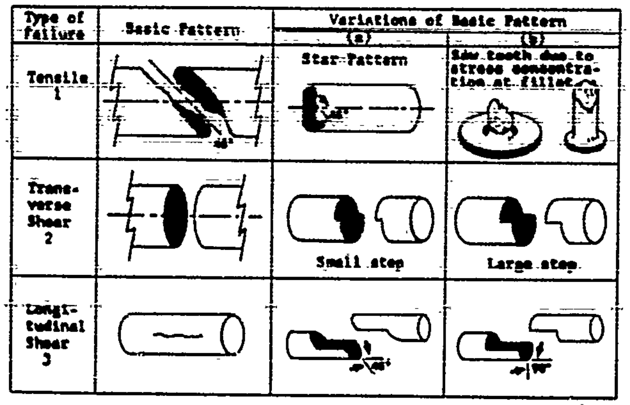


Figure H-10. Typical Torsion Fractures

siderably lower than the actual impact rate. Parts that fail under impact loading exhibit the same characteristics as parts that fail under normal static loading except that there is generally an absence of necking, and the fractures are more pronounced.

H-30. CORROSION.

H-31. A complete discussion of corrosion in metals is contained in the Aviation Safety Officer's Guide.

APPENDIX I.

AIRCRAFT FLUIDS AND FLUID LINES

I-1. IDENTIFICATION COLORS OF AIRCRAFT FLUIDS.

I-2. FUELS. Colors which apply to the types of fuel currently in use by the U.S. Navy are as follows:

1. Jet fuel (all grades) . . . . Green
2. 80-87 octane aviation gasoline . . . Red
3. 91-96 octane aviation gasoline . . . Blue
4. 100-130 octane aviation gasoline . . Green
5. 115-145 octane aviation gasoline . . Purple

I-3. HYDRAULIC FLUID. All hydraulic fluids currently in use in naval aircraft are red in color.

I-4. LUBRICATING OIL. Lubricating oils used in naval aircraft are amber in color.

I-5. FLUID LINE IDENTIFICATION.

I-6. Identification symbols and colors for fluid lines and other internal plumbing are shown in figure I-1.

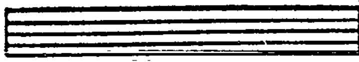
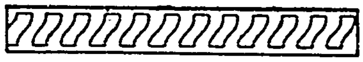
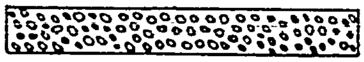
PURPOSE	COLORS	SYMBOL
Rocket Oxidizer	Green and grey	
Rocket Catalyst	Yellow and green	
Rocket Fuel	Red and grey	
Fuel	Red	
Water Injection	Red, grey, red	
Lubrication	Yellow	
Hydraulic	Blue and yellow	
Compressed Gas	Orange	
Instrument Air	Orange and grey	
Coolant	Blue	
Breathing Oxygen	Green	
Air Condition	Brown and grey	
Fire Protection	Brown	
De-Icing	Grey	
Pneumatic	Orange and blue	
Electrical Conduit	Brown and orange	
Warning Symbol		

Figure I-1. Fluid Line Identification

APPENDIX J.

PROPERTIES OF AIRCRAFT STRUCTURAL MATERIALS

J-1. GENERAL.

J-2. It is essential that the investigator be familiar with some of the properties of materials used in aircraft construction. It is often possible to determine the operating temperature of an engine or the intensity of a fire by examination of metals or other materials in the affected area.

J-3. PROPERTIES OF METALS.

J-4. MELTING POINT. Table J-1 lists the melting points of common aircraft metals and alloys. Correlation of evidence from several types of metals may be required to produce reliable temperature determinations.

J-5. DISCOLORATION. At temperatures below the melting point, some metals exhibit changes in color which are reliable indicators of the temperatures to which they were subjected. A few examples are listed below. The Naval Safety Center is a source of more complete information and technical assistance in this area.

1. Stainless steel starts to discolor at 800-900°F, from tan, to light blue, to bright blue, to black with increasing temperature.

Table J-1. Melting Points of Metals

MATERIAL	MELTING RANGE ($^{\circ}$F)
Aluminum 2024	935-1180
Aluminum 7075	890-1180
Aluminum 7178	890-1165
Brass	1600-2000
Cadmium	609
Copper	1981-2000
Chromium	3430
Iron	2802
Lead	621
Magnesium alloys	1202-1250
Manganese	2273
Mercury	-37.9
Molybdenum	4760
Nickel	2651
Selenium	428
Silicon	2605
Silver	1760
Stainless Steel 321	2550-2600
Stainless Steel 4340	2740
Tin	449
Titanium	3000-3040
Titanium alloys	2820-3000
Tungsten	6170
Vanadium	3150

2. Cadmium plating starts to discolor at 500°F.

3. Titanium discolors from tan, to light blue, to dark blue, to grey, and begins to form a scale at about 1100°F. Titanium becomes brittle when overheated 1600-1700°F for four to five minutes.

J-6. **PROPERTIES OF OTHER MATERIALS.**

J-7. AIRCRAFT PAINT. Temperature indications for aircraft paints vary according to the paint system utilized; however, table J-2 can be used as a rule of thumb for most paint systems.

J-8. AIRCRAFT FLUIDS. Flash points and auto-ignition temperatures of common aircraft fluids are shown in table J-3.

J-9. MISCELLANEOUS MATERIALS. Other useful properties of aircraft materials are as follows:

1. Glass cloth fuses at 1200°F.

2. Neoprene rubber blisters at 500°F.

3. Silicone rubber blisters at 700°F.

4. Outer braid of wire bundles deteriorates and becomes brittle at about 500°F.

5. Teflon insulation inner liner melts at 630°F.

6. Nylon spaghetti melts at 250-350°F.

Table J-2. Heat Characteristics of Typical Aircraft Paints

TEMPERATURE (°F)	INDICATION
400	Paint softens
450	Discoloration begins, paint starts to tan
500	Brown
600	Dark Brown
700	Black
800-850	Paint blisters
900-950	Paint burns off completely.

Table J-3. Properties of Aircraft Fluids

FLUID	FLASH POINT (°F)	AUTO-IGNITION TEMP (°F)
Fuels		
JP-4	-60	484
JP-5		440 to 475
AVGAS	-75 to -85	825 to 960
Engine Oil		
MIL-L-7808	400	1000
MIL-L-23699	450	1000
Hydraulic Fluid		
MIL-H-5606B	200	648

APPENDIX K.

REFERENCES

K-1. The following directives and publications contain additional information which may be useful to the investigator in some facet of the investigation.

1. OPNAVINST P-3750.6H, Navy Aircraft Accident, Incident, Flight Hazard and Forced Landing Reporting Procedure.

2. OPNAVINST 4790.2A, The Naval Aviation Maintenance Program.

3. BuAer INST NAVAER 0099A.

4. BuAer INST NAVAER 00.58B, Naval Aeronautical Material Reliability Program, Responsibilities and Procedures Concerning.

5. BuAer INST 11012.1, Air Station Planning Standards.

6. NAVAER 00-80C-501, Procedures for Aircraft Crash Fire Fighting and Rescue.

7. BuMed INST 6200.1, Armed Forces Medical Laboratory Facilities.

8. BuMed INST 3750.1, Aircraft Accident Boards, Responsibilities of Medical Officers Assigned as Members.

9. BuMed INST 6510.4A, Carbon Monoxide, Concentration of in Aviation Personnel; determination of.

10. BuMed INST 6410.1B, Ejection Seat Training, 6-EQ-2A, 6-EQ-2B, 6-EQ-2C, use of.

11. NAVMED P-5083, Methods for Preparing Pathological Specimens for Storage and Shipment.

12. NAVMED P-5065, Autopsy Manual.

13. BUMEDINST 5360.1, Decedent Affairs Manual.

14. U. S. Navy Flight Surgeon's Manual.

15. Naval Aviation Safety Officer's Course Texts, U.S. Naval Post-Graduate School, Monterey, California.

16. Aviation Crash Injury Research of Cornell University, Sky Harbor Airport, Phoenix, Arizona.

17. Technical order 1-58 dated 7 February 1958.

18. USAF Aircraft Investigator's Handbook, AFM 62-5.

19. International Civil Aviation Organization, Manual of Aircraft Accident Investigation (Doc 6920-AN/855), Fourth Edition—1970.

20. "Why Machine Parts Fail", Penton Publishing Co., 1951.

NOTE

Figure H-10, "Typical Torsion Fractures" from "Why Machine Parts Fail" is used by permission.

21. "Airplane Aerodynamics", Dommasch, Sherby, and Connelly, Pitman Publishing Corporation, 1961.

22. Aerodynamics for Naval Aviators, NAVAIR 00-80T-80, 1965.

23. Aviation Safety Officer's Guide.

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